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THE STAFFORDSHIRE IRON AND STEEL INSTITUTE.

PROCEEDINGS.

SESSION 1906—1907.

VOL. XXII.

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CONTENTS OF VOL. XXII.

PAGE.

First Meeting of the Session 1

Address by President (Mr. Wm. Somers) ... .. 2—10

Discussion on ditto ... ... 10—16

Second Meeting of Session 17

Paper on the Combined Influence of Certain Elements on Cast-iron by Mr. A. H. Hiorns ... ... 18—29

Third Meeting of Session 30

Paper on The Use of Gas for Heating and Re-heating Purposes, by Mr. C. H. Wall ... ... 31—48

Discussion on ditto ... ... 48—59

Fourth Meeting of Session 60

Paper on Internal Combustion Engines, by Professor F. W. Burstall ... ... 61—68

Discussion on ditto ... ... 68—76

Fifth Meeting of Session 77

Paper on Some Principles of Physical Chemistry and their Application in Metallurgy, by Dr. Alex. Findlay ... 78—97

Discussion on ditto ... ... 97—101

Sixth Meeting of Session 102

Resumé of Paper on Some Applications of the Steam Turbine, by Mr. F. Noel ... ... 103—107

Discussion on ditto ... ... 107—111

Seventh Meeting of Session 112

Paper on The Blast Furnace Practically and Theoretically Considered, by Mr. W. J. Foster ... ... 113—125

Discussion on ditto ... ... 126—132

Annual Meeting, 27th April, 1907 ... ... 133—135

Annual Dinner 135–140

Balance Sheet for year 1906 141

Rules ... ... 142—149

Officers for Session 1907—1908 150

Past Presidents 151

List of Members ... ... 152—169

List of Exchanges 170

Index ... ... 171—175

THE STAFFORDSHIRE IRON AND STEEL INSTITUTE.

SESSION 1906—1907.

The First Meeting of the Session was held at the Institute, Dudley, on Saturday, the 27th October, 1906.

The President (Mr. William Somers) occupied the chair. There was a large attendance of members.

The minutes of the Annual Meeting, held on the 28th April last, were read, approved, and signed.

The President announced the death of Mr. Henry Parry since the last meeting, and referred to the loss the Institute had sustained by Mr. Parry's decease.

The following were elected member of the Institute: W. Baker, E. J. Bush, T. K. Fellows, S. Moore, J. Rollason, F. S. Wilkinson, and Frederick Wood.

The President then delivered the following address :—

ADDRESS BY THE PRESIDENT

(Mr. WILLIAM SOMERS).

I think this address will be best described as a "round-about paper," for so much that is good and valuable has already been said by past presidents of this Institute, whose ability and knowledge are so much greater than my own, on all branches touching the subject of iron and steel, that I feel diffident about attempting any special subject.

All who have to any extent studied the history of iron and steel must inevitably have been struck by the fact that the development of iron has always gone hand in hand with the advance of civilisation. Wherever and whenever the knowledge and uses of iron have been in evidence there has followed general progress and consequent culture.

From the earliest times we find that the uses of iron were known at least in part, for in Genesis we read that Tubal Cain was "an instructor of every artificer in brass and iron." We know it formed part of the knowledge of the Egyptians, whose civilisation was remarkably advanced; also from ancient sources we find that the best steel came from China, probably the oldest and most civilised country of the world.

In early English history, the most important trade was the working of tin and iron, the most important workmen were the smiths who worked up the metal into armour and swords, spearheads, spurs, and horseshoes; for the English were never a purely pastoral wandering people like the Israelites, or a cultured community of masters and slaves like the Egyptians.

Living on an island the English always had to be prepared to defend themselves by the edge of the sword against fierce invaders. When every English gentleman (whether priest or layman) was a soldier, his most valued possession was his equipment, without which he could not hope to gain or retain any worldly belongings, whether it was land, money, or a wife. A man's safety in those "good old days" depended on the temper of his sword and his knowledge in the use of it. The man with the best weapons was, as a rule, the man to master his fellow-men and make them his followers, and the man with the best suit of chain armour was best able to defend himself against strong and cunning adversaries.

Hence from the earliest times it was through the use of iron and steel that life was fortified and prolonged, and men given time and opportunity to develop the best in them.

To come to more modern times, when the days of the old coach were drawing to a close and the great new iron locomotives with their steel rails were beginning to traverse the land, men, through better means of access to their fellow men and better knowledge of places and affairs, were forced to lay aside many of their old narrow views, prejudices, and superstitions.

Thus the iron monster of the railroad helped forward education in the best sense and helped men to greater enlightenment.

At sea, as on land, speed and durability made tremendous strides, and in our warships were especially marked. In 1859 the French built the first iron-plated frigate, which started a new era in the naval world. Our Admiralty at once followed suit and launched in the following year our first iron-clad man-of-war. Henceforth each new ship was plated thicker and thicker until the armour was as much as 30 inches thick. Later, steel, which had three times the strength and resistance of the iron of the first ironclad, was substituted. Though our Navy has increased so enormously in power and speed, it has not done so in proportion to the trade it has to protect, which is a much more important fact now than then, owing to the increased population, as we should find out to our sorrow if ever we lost command of the sea. Our merchantmen and passenger boats have also materially changed, whereas the hull was then of wood, now it is of iron or more often steel; also many of the masts are of steel, and most of the rigging, and labour-saving machines are much in evidence.

Improved means of communication naturally led to improved business and the subsequent necessity for wider and more complete education. Where only one man was able to read and write and reckon, hundreds soon learnt to do so, for they had to learn or starve as competition became keener. At first, in the best schools, practical education was considered superfluous and only classical subjects were taught, and it is only now during the last few years that schoolmasters have awakened to the idea that a practical education is urgently needed and far exceeds in usefulness (at any rate for a business career) a merely literary education.

Where a few years ago science was treated as an outside subject, it now universally forms part of the regular curriculum, which shows a long step in the right direction.

The subject of technical education is one the importance of which my predecessors in their addresses have never failed to impress upon you, and I may therefore be pardoned for dwelling at some length on this subject, for it is one the practical weight of which it would be difficult to over-estimate. Unfortunately we, as a nation, have not taken this matter seriously until lately, the inevitable consequence being, we are forced with sorrow to confess, that we are left behind by our continental neighbours in the educational race.

This is an extremely serious matter, as it so ultimately concerns our future trade, which will be in the hands of the younger generation, who receiving an education unequal in quantity and quality to that of men who will be their competitors, are handicapped from the start of their career. Our schools and colleges, where practical technical education is looked upon as all important, are few and far between compared with those of our competitors across the Channel.

Though I think it is a mistake to depend wholly on classroom knowledge and to entirely substitute it for the old idea of long apprenticeship, still it has many advantages over our present system. The happy medium which most nearly approaches what is needed is I think a good technical education supplemented by practical workshop experience. The one without the other leads to a lack of commercial knowledge, that is to say, the consideration of the cost of production.

The old idea of the absolute necessity of a seven years' apprenticeship to one master in one branch of business, which often means the waste of several most valuable years, is rapidly giving place to the desire for a more efficient and expeditious system—a system whereby the really sound knowledge of the sciences underlying the employers' industry can be imparted to the student, so that when he enters a works later on he can bring his well-trained brains into the work; and employers must see that they are given a fair chance to make use of their knowledge.

At first England was far ahead of all other countries in the possession of technical schools and institutions where the best appliances and inventions of the day were to be seen and used, though it is only within the last few years that the artisan class has begun to know of and appreciate the blessings of such places. Such education is necessary to every man who hopes to be a success in commercial life.

Of course there have been and we hope always will be brilliant exceptions to this rule—men endowed by nature with special gifts, who possess in abnormal degree perserverance, ability, and enterprise. Such men, with the least chance in life, always have risen slowly but surely to the top, have dominated their followers, and bent circumstance to their will. But to ordinary mortals the lack of a good practical education is a terrible handicap.

Public schools are much to blame in this respect. The present is a scientific and business age, but public school education is very little different to what it was in Tom Brown's days, when a smattering of Latin and Greek added to the manners of an English gentleman was all that was required. A boy turned out in the world with such an education is more hopelessly "out of work" than the dull-witted labourer with a job. As a rule it is the experience of employers that a public school boy's success in proving himself of any value is in spite, rather than because of his education. Efficient technical education is essential to this country if she is to maintain her equality, not to mention superiority, to foreign nations who enjoy a higher standard of useful education.

Great changes in every branch of industry are to be foreseen approaching in the near future, and every wise man should be prepared to face altered conditions in altered circumstances. The man who will be in the front is he who can meet, as it arises, every new move with open and unbiassed mind. To do this he must have, besides sound practical education, a knowledge of the underlying principles of mechanical action and an adaptable acquaintance with physical science and chemistry.

In this pre-eminently commercial country of ours, and in this keenly competitive time, those who possess only a slight knowledge of industrial science cannot hope to successfully compete with foreigners, whose acquaintance with such subjects is much wider and more practical. Yet many men are striving wearily and with diminishing prospects to compete against such as these.

One remedy is for everyone to strive to obliterate this unequal struggle by enabling men and employers to enjoy to the full all possible educational advantages. Let those who wish to become managers of works be trained for that purpose at the Birmingham University—a University upon which we may well congratulate ourselves as being within a reasonable distance from our homes. Let him take there not merely a session but if possible three or four years in the engineering, mining, and metallurgical section.

I do not go so far as to say that when a youth has gone through such a course of training he will be fitted to become a manager, for this knowledge must be supplemented with a thorough practical knowledge of the subject and also how to manage the men themselves, and of this last point I reserve a few remarks until later in my address, but I do say that the training he gets at the University will help him to succeed in life.

I do not know how many here present have visited the University, but those of you that have been fortunate enough to do so will no doubt have been struck by the idea of the authorities to let nothing stand in the way of giving to the students as practical a training as is possible; the working models and the small furnaces all being worked on the latest styles and with the latest appliances; whilst the greatest attention is paid to the laboratories, fitted with accurate and elaborate instruments.

It was due to the discovery by the enterprising Dud Dudley that pit coal was used as a substitute for charcoal in the manufacture of iron, and immediately he showed that this was a profitable way of smelting the iron, Staffordshire became a great iron district on account of the proximity of the ore to the fuel. We are sometimes told that we have seen our day, but I venture to think that Staffordshire can produce to-day as good work as ever. But I am not going to deny that we are severely handicapped by having no waterway to carry our goods to and from the coast. Why should we lose the position which we have occupied for so many years?

We are told we have sufficient coal supply for generations. We have, I may safely say, among the ironworkers in Staffordshire, some of the best of Britain's workmen. Why then should we be compelled to move to the sea coast? The time has come for us not to ignore our difficulties but to meet and overcome them. This great question of how to keep our trade in Staffordshire is one that we surely ought to discuss and strive our utmost to constantly keep to the front. We may possess the best managers, the best workmen, and the best machinery, but of what use is it unless we can secure the trade? I am extremely glad that at last we have had a Royal Commission sitting to discuss the canal question with regard to England as a whole, and that certain gentlemen in this district had an opportunity of expressing their views. I am sure we all hope and trust that the result will be a waterway that will stimulate our trade and help us to regain the position we once held.

I should like to say a few words about the present condition of our canals. They are widespread and numerous, and ought to carry on their waters a good proportion of the merchandise of the country. They do not do this owing to the fact that they are practically derelict—they are choked with vegetable growths, their locks are in many cases unworkable through wood-rot and neglect, and their water supply has been allowed to dwindle to a pitiable extent. This is all the more serious because they often form valuable connecting links between places of industrial activity. These deplorable facts are due in main to two causes—the rise of railway companies and their ensuing policy concerning canals, and also the want of foresight on the part of the builders of canals.

Before railways became of importance, the canals which were constructed very rapidly between 1761 and 1830 did a very large and profitable amount of the carrying trade of the country—for they were a tremendous improvement on all former means of transport; but when the railways, with their accelerated powers of quick carriage rose so suddenly into prominence, the canal owners took fright and thought their day was over. On the other hand, the railway companies saw in the canals dangerous rivals to their carrying trade and prosperity, and consequently were as ready to buy up the canals at low prices, as the canal owners were to sell them. Hence between 1845 and 1847 the railway companies took over the control of 948 miles of waterways, which increased in 1888 to 1,375 miles. We can very clearly see the result in the following statistics from Henry de Salis's book published *last year*:—

Great Central Railway owns canals in five counties. The author's comment is: The trade done on any part of the canals is very small.

Great Northern Railway owns canals in the Midlands and East of England. The comment runs: There is not much trade done.

Great Western Railway owns or controls nearly a dozen canals, and Mr. de Salis adds: There is not much trade done on any of the Company's canals.

London and North-Western Railway owns five canals and controls two others. With the exception of the Lancaster Canal there is not much traffic on any of the Company's canals.

Midland Railway owns two canals. On one of them there is a coal carrying trade, but the other is not much used, and, as a whole, is in an indifferent condition.

North-Eastern Railway owns three canals and controls one other. There is very little trade done. Of one it is reported: The upper part appears to be practically derelict.

South-Eastern and Chatham Railway owns one canal. Not much trade, but in fair condition, is the author's remark.

In striking contrast to this, we find that canals *not* owned by the railways do a good trade and are kept in good condition.

To return to the other reason for their decay—the lack of sagacity on the part of the original makers of canals. Nearly all of them are constructed on different plans, and are of different shapes, and will only accommodate the special sort of boat built for each respectively; probably the makers never dreamt that some day their waterways might form a network of communication. Owing to this fact the canals are heavily handicapped in usefulness, as so many unnecessary hindrances are added to their none too quick means of transport.

Now the lines and vehicles of all railways are practically alike and can consequently enjoy the privilege of running over each other's lines and through tunnels with all the subsequent advantages of saving time, money, and wear and tear. If, as is the case with canals, each company had gone their own way and constructed engines, carriages, trucks, tunnels, and lines after their own special size and pattern, making it impossible for one company's trains to run on any lines but their own, what a great deal of trouble and confusion, waste of labour and money and time would have ensued. Think of the complicated bookings, the endless changing, the awful language, and the wear and tear in transporting goods—all of which disadvantages the canals are labouring under.

What the the result of the Commission will be I cannot foretell, but I think everyone here will agree that it is detrimental to our interests to have so many of our waterways in the hands of railway companies, who on their part have no desire to see them prosper, and so long as they control these waterways, so long will our manufacturers be burdened and hampered by heavy rates of carriage on goods, which on the Continent are conveyed at half the cost. Ample and cheap means of transit is the prime necessity for us in Staffordshire, and I sincerely hope that we may live to see it.

With all these disadvantages which we experience with the difficulties of transport, I think every encouragement should be given to those firms who are enterprising enough to extend their plant and embark on a new venture which gives greater employment to the working classes of this district; but I am sorry to say that in certain districts, the attitude of the Assessment Committees, in their valuations for rating purposes, has been such as to give employers serious thought of transferring their works to some place where they may obtain the double advantage of a good waterway and also a more lenient assessment. I think this matter is one of the greatest importance to us. I do not wish to accuse every Committee of taking this attitude that is slowly but surely doing its best to kill Staffordshire trade; but we have heard whispers of works being removed owing to this cause, and I am sure the district cannot afford to lose any industry.

I will take one case within my own knowledge and within ten miles of this very town, where a piece of machinery was put down which enabled the firm to produce work they had never produced before, it enabled them to employ more men, and it also enabled them to bring work into the Staffordshire district, which, owing to the want of this very machine, had in former days gone elsewhere. The class of work could actually have been done cheaper at some town near the coast, or on some waterway; but it was placed in this district simply and solely for sentimental reasons; the works had been started in this district, and had grown here, and therefore would be kept in this district.

Hardly had the new machinery been started when notice was given that the assessment of the works was to be raised; this was expected, but when the figures came to be known, showing that the assessment had been practically doubled, an appeal was instantly lodged, the Committee refused to see the machine or meet the employers, but, eventually, the assessment was settled. I am afraid that many other firms can complain of this treatment; had that assessment been persisted in this particular firm would in all probability have removed this machine, and this would have meant, as it has before, simply the beginning of the end, as it is, it has caused that firm to abandon for a time all thoughts of another venture being started, at any rate, in this part of the country.

We, as an Institute, comprising members of the most important industry of the world, a trade upon which all other work depends, should do whatever lies in our power to protect such industry and further its prosperity. I therefore make no apology for dwelling on this point of assessments, and express my pleasure at noting that the Chambers of Commerce are taking the matter up, and I trust they will be successful in obtaining some easement in favour of industries and particularly of new ones in the gross assessment for local rating purposes.

In conclusion I should like to say something about the social condition of our working men. Given equal terms I do not believe that there are any working men in the world who can beat those of Staffordshire, but it is only fair that the conditions under which they work should be made as good as is possible if the best work is to be expected of them.

Methods must be introduced into the system of management, such as will raise the physical condition of the men to a higher state of efficiency. For instance, though it is not within the power of every works to provide swimming baths, there is generally enough water at hand to supply a washing place for the men. Likewise, it is generally within the scope of the managers, perhaps with a little contriving, to provide a mess room where the men can have their food cooked or warmed, and which room could afterwards be used as a reading room. Unless employers look after the welfare of their employés they cannot really blame the employé for not taking any more interest in his work beyond the fact that he is paid for it, whereas they ought to feel that they, in common with the managers and employers, are all working to maintain our national industry and that Capital and Labour are dependent upon each other, and that the relationship between employer and employé is not antagonistic.

Now with regard to economy in a works. One of the best methods of studying this subject is to visit other people's works, see their methods of doing work and compare them with your own. Many cling to the idea that to close your works to visitors and keep your ideas to yourselves is true economy. I think that is a great mistake. You lose considerably more than you gain by such a policy. There are really very few " secrets " in the iron trade, and generally you find these so-called " secrets " very badly kept.

Another point in economy is that whereas in our grandfathers' time, when changes were few and slow, a tool or piece of machinery was required to last a lifetime. Nowadays, when a machine is obsolete, if it is still in as good condition as when first made, there is waste somewhere, for the maker must have used better material and workmanship than was necessary.

We are apt to be extravagant in our ideas of good workmanship—it is a very good thing to see a " well-finished " article. While our competitors do all they can to accomplish cheapness, we waste ourselves making over-expensive goods, which when obsolete are still serviceable, instead of being only fit for the scrap heap.

Of course, our competitors' average of excellent work is much below our own, but so also is the average price.

Managers will have to be on the strict look out to avoid any waste; the greatest lesson with regard to this was learnt by ironmasters when they discovered the enormous saving by recovering the chemical by-products from the blast furnace. One of the ideals of modern industry is that nothing shall be wasted. The amount of fuel that is wasted year after year is something enormous, and although gas-producing plants have been laid down and furnaces re-modelled, we still find heaps of room for more economy.

Economy in time and labour can be accomplished by having a system whereby a proper cost of each individual piece of work can be obtained, only by this means can a manager be in a position to find leakages if any exist and apply remedies when they may be necessary.

This question of costs is absolutely essential if a firm wishes to continue in prosperity, for it is only by this system that losses, in many cases, are detected.

As we have seen to-day—as compared with the time of our grandfathers—the Staffordshire iron manufacturer has many difficulties to overcome. But on the other hand we have the great advantage of the increasing accessibility of scientific knowledge. And it is upon the adequate employment of this knowledge, in conjunction with a careful system of works organisation, whereby wise economies may be effected and a perfect understanding prevail between the master, managers, and men that we must for the future depend, in order that we may resist the competition of the foreigner and maintain the reputation of Staffordshire throughout the world.

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THE DISCUSSION.

Mr. Walter Jones, in moving a vote of thanks to the President for his address, said: It is often a difficult matter to prepare a Presidential Address, but Mr. Somers has certainly given us something to think over on this occasion. There are one or two points in the paper I might touch upon. On page 4 he says: "The old idea of the absolute necessity of a seven years' apprenticeship to one master in one branch of business, which often means the waste of several most valuable years, etc , etc." Now I do not agree that an apprenticeship is a waste of time. I think it is matter for regret that there are not more apprenticeships now. The old method of apprenticeship never struck me as being a waste of time, but quite the reverse. Is any member present to-night who has served as manager or in some other responsible capacity for say seven, fourteen, twenty-one, or even twenty-eight years who does not feel that he has still something to learn about that very department or branch? For myself, I have been making a study of certain things in my business for longer than any of the periods I have mentioned—for thirty years—and I feel more ignorant every year I live. I think the time of an apprenticeship, if the apprentice has anything like a good place, can scarcely be considered wasted. The "expeditious systems" of acquiring knowledge, which apparently meet with the President's warm support, too often only lead to very superficial knowledge. My experience at my works is that a good many men have a smattering of a number of things without knowing any one thing well. I will turn now to a remark on page 8. The President, speaking on the canal and railway question, says: "I think everyone here will agree that it is detrimental to our interests to have so many of our waterways in the hands of railway companies." I believe he is quite correct, and will, I think, carry all of us with him. It is impossible to feel or speak too strongly on this most important subject. The manner in which the waterways of this country, once a very valuable asset of the trade of the country, have been purposely neglected by those in whose hands they have been is nothing short of a national scandal. Mr. Somers is quite right in attributing the desuetude into which they have fallen to the studied policy of the railway companies. The canals, or most of them, are practically governed or owned by the railways, who consider it to their own interests to prevent water carriage. It is not the interests of the community that the railways have considered or are considering in this matter. They judge it entirely from a dividend-making policy. On the continent, which is well served with inland water carriage, the difficulty which we experience is non-existent. It is got over by the nationalisation, to a very large extent, of both the railways and the canals. As I have said, this matter is a very important one; it is one which manufacturers and commercial men would be wise to consider and examine from every possible point of view. The desire that the carrying lines of the country shall be taken over by the State and worked for the benefit of the community at large, is one that must come increasingly to the front as a matter of what one may fairly term practical politics. Passing for a moment to another matter dealt with by the President, he referred to the subject of works assessment. He instances a case where a works assessment had been "practically doubled" owing to the laying down of certain new machinery, and he states that he believes that "many other firms" have to complain of the same treatment. I had some difficulty concerning this very problem at my own works some time ago. I think that traders generally are handicapped very often by over-assessment and over-rating. It is with respect to the establishment of new manufacturing industries that the shoe very frequently pinches. The matter of railway conveyance and railway rates is, however, even more important. I will give you an instance of just what I mean. I recently had a gentleman at my works who was interesting himself in the establishing of a new works in this country. His firm was a very large one, with a capital of something like £2,000,000 sterling, and they were desirous of starting a works in Great Britain connected with the iron trade. They had hunted the country over to find the best site, and had at last elected to start at Hull, in order to be free of railway rates. They found that wherever they went in the Midlands they would be at the mercy of the railway companies, and it was the same in some other parts of England, so they determined to go on to the coast straight away. Thus you will recognise that the cost of transit, particularly when starting a new industry or a new works, is a very serious consideration. The firm I am referring to would lay down a work covering probably seven or eight acres. Abroad, the cost of transit is only something like one-half of what it is here. It is an astounding fact, but absolutely true, that goods can be sent cheaper from the centre of Germany right into the centre of England than the railway companies will convey the same goods from the centre of England to our own seaboard. And hundreds of other instances might be quoted of the same kind of treatment. Thus the Institute will observe how pressing and serious a matter this question of railway carriage still is. The President made some remarks towards the end of his paper about works economy. One conclusion of his I must take the strongest exception to. Referring to the strength of machinery and machine parts and of how long a piece of machinery will last he ventures this remarkable—I can call it nothing less—pronouncement: "Nowadays when a machine is obsolete, if it is still in as good condition as when first made, there is waste somewhere, for the maker must have used better material and workmanship than was necessary." Let me say at once that I don't agree with the President's conclusion. Waste, rightly so-called, should be avoided, and the President does well to direct attention to works' waste. But, when we come to the matter of the quality and strength of plant, I contend, and I believe my position to be sound, that it is better to have a piece of machinery of an endurance that perchance may last a lifetime, rather than have an inferior or lighter make that may fail you, perhaps, at the most critical point in its work. I don't think a machine can be too good. Rather, I find, the trouble nowadays is that you cannot depend upon what you buy. Cheap things are invariably dear, and never more so than in engineering work. I have expressed myself rather freely this evening; I may be wrong, and our accomplished President right, but the views which I have expressed are my own, and I alone am responsible for them. In conclusion, I desire again to congratulate both the President and the Institute upon the able manner in which the Institute has been addressed upon this occasion.

Mr. J. W. HALL, in seconding the vote of thanks to the President, said: I should like to touch upon the matter of apprenticeships, which was one of the points raised in the President's address. There are two ways, to my thinking, in which the subject of the old apprenticeship system may very well be viewed. In considering the pros and cons of the system, the first thing to be thought of in seeking to arrive at the best judgment is, what is the intention regarding the ultimate destiny of the youth to be apprenticed? Is it desired that he should become a handicraftsman, or is a place as foreman or manager wanted for him? If manual dexterity is the chief desideratum for the youth under discussion then, unquestionably, the old system had nothing to compare with it for excellence. A seven years' apprenticeship would not then be too long for the excellence of the results produced. But if what is desired for our youth is a foreman's or manager's place, then I do not think that the apprenticeship system is the best way to accomplish our ends. In such a case as this what is required is a training of the mind rather than the muscles. You want to educate a youth to lead others and to gain control and ascendancy over others. An apprenticeship would be of little use for this end. The Technical School or the University, following, if possible, upon a public school career, would be the methods I should recommend in a case of this kind. There is another view which may be taken of this question. It is this—the ultimate intended occupation of a youth should direct the early course of his educational career. The President has complained of our public schools, and declares that "Public school education to-day is very little different to what it was in Tom Brown's days." And he continues "A boy turned out in the world with such an education is more hopelessly 'out of work' than the dull-witted labourer with a job." I differ a good deal from the President in this estimate of the value of a public school education. There are some things which are learned better at a public school than anywhere else. One of these things is the management of one's neighbour or of those who may by and by be under one. A captain of his school, or a captain of his house, learns to manage men. If a boy, as a boy, can manage and lead boys, when he becomes a man he will be able to manage and lead men. In this particular a public school training is invaluable. There is another thing such a boy learns, and it is this, he learns that to a wise degree he must have respect to other people's opinions. Though the temptation in the opposite direction may be strong at first, he gradually learns that his school is not the hub of the universe. This knowledge broadens his view of life and things and fits him to occupy his correct position in the world of men. If a lad is by and by to enter a works as a manager or in some allied position of authority, he will want a foundation of something else besides technical education. That is my point. Technical education is one of the fundamentals to success unquestionably, but it is not all. Many a highly-trained man is useless if you put him into a position as manager. And, for the reason that he lacks the ability of the management of his fellows such as I have impressed. Concerning the subject of our canals, which has been referred to both by the President and the ex-President, I fully agree with what they have both said. I should imagine that every trader in the country, almost without exception, must long before this have become persuaded that it was a national evil that our English inland waterways are in the hands of the railway carriers. Trade, at any rate in the Midlands, and in some other parts of the country too, will never be placed on the footing it should be until there is an alteration in the present state of things. And it is an accepted axiom in commercial circles that the railway companies do not want the canals to prosper or to be used to any considerable extent. I will give you an illustration in point, and of the truth of which I have no doubt. An official associated with the management of a large canal owned by one of the railway companies had for some time been anxious to have a particular stretch of the waterway cleared out, but he had repeatedly tried in vain to get attention paid to the matter. The other day, in desperation, he determined to himself go to headquarters to ascertain the reason for the delay. He went to headquarters, and in reply was told "We know the canal is fouled, but don't you trouble, that's all right." Now this is very probably not a solitary instance. It is a very great misfortune that ever the waterways were passed over to the railway companies, and something must be done to create a change. If the Board of Trade, or Parliament, would do something to effect a radical revolution in the present situation, they would be doing one of the most conspicuous things to help the trade and commerce of this country that has been accomplished for many years. I believe—at least I hope—that something practical may be expected to issue from the recent Report of the Parliamentary Commission upon this subject. The suggestions set down in the report are the best, so far as I have observed, of perhaps any that have been presented, and appear to carry the matter further forward than anything that has gone before.

Mr. L. D. THOMAS, in supporting the vote of thanks, congratulated the President, but said he should have liked, if the President in the commencement of his address, had given more attention to the early history of British ironmaking. The matters dealt with in the address were very practical, and some of them, particularly canalisation reform, were very desirable of accomplishment. He believed the time was not distant when certain of the reforms sketched would be carried through.

Mr. JAMES PIPER: I should like also to add my praise to that of previous speakers respecting the practical excellence of Mr. Somers' address. In certain particulars, it was admirable. There is one point I should like to touch upon without detaining the members longer. It is with respect to the President's remarks relative to works' assessment. In my opinion, much of the trouble from which we admittedly suffer in connection with this most vexatious matter, lies at the door of the works owners and factory owners themselves. Instead of, as at the present time, being often only too anxious to get out of the duties of acting as overseers, they should show themselves willing to fill the office of overseers, and sit on Poor Law Boards. Then, if I mistake not, they would see to it that their works were not over-rated.

Mr. **William Kendrick**: I should like to be permitted to heartily support the vote of thanks to our president for his admirable address. I was particularly struck by the appropriateness of much that he said concerning the existing deficiencies in our educational system. I quite agree with the view that he takes of the seriousness of this question. He said that "We are being left behind by our continental neighbours in the educational race," and again, that the matter "ultimately concerns our future trade, which will be in the hands of the younger generation, who, receiving an education unequal in quantity and quality to that of men who will be their competitors, are handicapped from the start of their career." It seems to me that the chief defect in our national educational system at present, and where the wastage comes in, is concerning the boys after they have attained the age of fourteen years, and have left school. At fourteen a boy, I speak of the bulk, is anxious to be rid of school and of all school duties, and he does his best to be rid of study, and goes to work. We shall never do much good in checking this tendency or bringing about reform, and so utilising the facilities which are now provided in every town, and in every county, for continued study, and for what is termed higher education, until attendance at evening classes is compulsory. Boys of fourteen upon beginning work should be compelled to attend evening classes until they attain the age, say, of sixteen years. I am persuaded that in no other way shall we keep pace with our continental rivals.

The vote of thanks was put to the meeting and passed.

The **President**: I thank you very much indeed for the kind manner in which you have received my address. It is often said that the discussions are often more valuable than the papers read here. Certainly to-night there have been some remarks made in the course of discussion which I shall find useful. Respecting the ex-President's criticism of my views upon the passing away of the apprenticeship system, I still feel that I cannot abate anything I have said in my address on that matter. I still feel that in ninety-nine cases in a hundred it is, as I have said, matter for satisfaction that the apprenticeship system is giving place to the desire for more efficient and expeditious methods of learning a trade. Mr. Walter Jones also canvassed my judgment relative to the strength to which machinery and plant should be made. Mr. Jones is an authority here and one has to be careful how one differs from him. I am prepared to admit at once and freely that there is some machinery—perhaps much—which we cannot have, upon occasion, of too high a standard. But, notwithstanding this concession, I still hold that in many cases specifications call for work of an absolutely greater strength and quality than there is any occasion for in respect of the performances which will be required of it. In such cases, however, it is easy to see that they are not the producing engineers or ironfounders who are to blame. It is the user, *i.e.*, the buyer, or the specifying engineer, with whom the responsibility rests. My remarks had reference mainly to consultant and specifying engineers, and such like. But to producing engineers also, I would say, considering that foreigners are making lighter and cheaper machinery and are capturing British orders, if we are going to compete at all we must not be above taking a leaf out of their book, and, so long as safety and efficiency is not compromised, must keep our specifications down Machinery, I am convinced, can be sufficiently good without being unduly heavy. America has shown us marvels in this respect. Mr. Thomas wished that I had found a greater space in my paper for recording early British accomplishments in the history of iron manufacture. The fact was that I purposely avoided any detailed reference here, since the ground had been so frequently travelled previously. I have to again thank you for the kind manner in which you have received my address.

The meeting now closed.

The Second Meeting of the Session was held at The Institute, Dudley, on Saturday, the 17th November, 1906.

The President (Mr. William Somers) presided over a large attendance.

The minutes of the previous Meeting were read, approved, and signed.

Messrs. C. B. Groocock, Samuel Harris, and Charles E. Stanier were elected members of the Institute.

Mr. Arthur H. Hiorns read the following paper, which was illustrated by a number of enlarged micrographs :—

COMBINED INFLUENCE OF CERTAIN ELEMENTS ON CAST-IRON.

By ARTHUR H. HIORNS.

In a paper read before the Society of Chemical Industry in January of last year (1905) the results of an investigation on the "Effects of Certain Elements on the structure of Cast-iron" were given. Pure cast-iron was taken to be pure iron associated with pure carbon at about the saturation point, which is 4·25 per cent. To this was added separately varying proportions of single elements in a practically pure state. Each alloy when melted was kept in quiet fusion in a covered crucible for some time, then allowed to solidify and maintained at a temperature of about 1,100° C. for several hours. It was afterwards allowed to cool very slowly. A section was cut right through the centre, then polished and etched with a solution of iodine in alcohol.

The object of keeping the alloy at the above-mentioned temperature was to give ample facilities for the carbon to separate out as graphite, and in the absence of elements other than iron and carbon the separation was found to be practically complete. In the presence of other elements the separation of carbon was more or less interfered with. It was also proved that with pure cast-iron, when cooled somewhat rapidly to below 1,000° C., the carbon did not separate as graphite, but remained practically in the combined form.

From these results it appears that the separation of graphite from highly-carburised iron largely depends on the exposure to a high range of temperature for a sufficiently long time, and that if the cooling be made sufficiently slow practically the whole of the carbon separates out as graphite. These results have now been confirmed by other workers.

Influence of Silicon.—The effect of silicon on iron is to form with it a chemical compound which, according to Carnot and Goutal, has the formula Fe_2Si., and in rich ferro-silicons $FeSi$. When iron which contains much silicon is microscopically examined the silicide is observed in characteristic crystalline forms, but in ordinary cast-irons it probably exists as a solidified solution in the iron and forms part of the structureless matrix from which graphite has been rejected. The silicon, therefore, being chemically united with the iron is rendered almost inert, so far as the carbon is concerned, and the carbon is free to act with regard to the iron much as though the silicon were absent, and therefore its mode of existence depends largely on the conditions of cooling. The iron crystals which contain the silicon must, however, be harder than the crystals of pure iron, since nothing can be added to iron to make it equally soft, much less can the added element make it softer. Hence it is concluded that the separation of graphite from its solution in iron after the latter has solidified is chiefly a function of time and temperature. To further test this view a portion of cast-iron, containing one per cent. of silicon, was quenched in water from a temperature of 1,100° C. The whole of the carbon was found to be in the combined form or with only a small trace of graphite. The silicon did not, therefore, cause the formation of graphite, nor prevent the carbon remaining in the combined form. Moreover, when graphite has once had sufficient time to crystallise out at about 1,100° C., subsequent quenching does not cause it to pass into the combined form at any lower temperature.

Professor Heyn, of Charlottenburg, in an important paper on the Constitution of Iron-Carbon Alloys, suggests that while pure cast-iron tends to supercooling, and the stable form (ferrite plus graphite) is reached only gradually, silicon works in opposition to supercooling, and therefore promotes the stable condition; in other words, silicon makes the metastable state more unstable, and therefore lowers the temperature at which graphite may be separated. On the other hand he considers that manganese has just the opposite tendency.

Influence of Manganese.—The effect of manganese on the condition of carbon in cast-iron is doubtless due to the fact of its having the power to dissolve carbon on its own account, and therefore to increase the proportion of combined carbon in the iron. Moreover, manganese has a special affinity for silicon and sulphur, which form silicide Mn Si. and sulphide Mn S. respectively, when the manganese is present in sufficient quantity, say up to 2 per cent. When it is present in larger proportion it forms double carbides of iron and manganese, but some of the carbon is combined with the iron to form free cementite. The quantity of sulphur usually present in cast-iron containing sufficient manganese is probable wholly in combination with the manganese, forming the compound Mn.S., so that manganese in cast-iron may be combined with silicon, sulphur, and carbon, but probably not with phosphorus.

Manganese added to pure cast-iron tends to prevent the separation of carbon as graphite, to keep the carbon in the combined form, and to prevent the formation of crystals of ferrite. A sample of cast-iron was made containing only iron, carbon, and 1·5 per cent. of manganese, allowed to solidify and kept for several hours in a covered crucible at a temperature of 1050°C. It was then allowed slowly to cool. Notwithstanding the slow cooling, the metal was white, hard, and free from graphite.

Influence of Sulphur.—Sulphur, even when present in cast-iron in small quantities, exerts a considerable influence, and although the proportion of sulphur usually found in foundry irons is small, yet relatively small varations in sulphur content may entirely change the character of the iron under ordinary conditions of cooling. It exists in iron as a sulphide, and when manganese is present, as a sulphide of manganese. The former is readily fusible and decomposed at high temperatures, the consequence being that when the metal is slowly cooled from a high temperature a considerable proportion of the sulphur escapes as a gaseous compound, giving the metal a spongy texture. In the presence of manganese the sulphur unites with that element in preference to that of iron, and as the sulphide of manganese has a high melting point, the sulphur is not liberated in the gaseous form, so that blowholes and red-shortness are largely avoided. The tendency of sulphur in cast-iron is to neutralise that of silicon ; it acts the same way as manganese in keeping the carbon in thie combined form and promoting strength and rigidity. For strong metal the sulphur should not exceed 0·1 per cent. If we consider that other elements are usually present, such as silicon and manganese, each of which is capable of uniting with sulphur, we see how complicated the effect may be, and this accounts for the vagaries of sulphur in different brands of cast-iron.

It is generally observed that sulphur in pig iron increases with an increase of combined carbon, but this increase may be partly due to the diminution in the amount of silicon, which tends to remove sulphur and prevent its uniting with the iron. A slow temperature favours the retention of sulphur and a high temperature its expulsion. When sulphur exists in iron as sulphide of iron, which is moderately fusible, it is likely to retain the liquid state after the general mass has become solid. Now sulphides tend to segregate in the middle and upper part of a casting, but they are sometimes found regularly distributed through the mass. Stead has found that sulphur in hematite pig with little manganese is greatest in the middle portions, while in a pig with 2 per cent. manganese the sulphur is greatest in the upper and outer portions. Moreover, when the sulphur is all combined with manganese the carbon may separate out as graphite and produce grey instead of white iron. The general effect of sulphur in cast-iron may be summarised as follows:—

In virtue of a fusible sulphide of iron, the iron becomes more fusible and presumably more liquid. In consequence of the inducement to retain carbon in the combined form the metal is harder. For the same reason the shrinkage is increased. As white iron is the densest form of cast-iron, sulphur tends to increase the density. With much sulphur and in the absence of manganese and the prevalence of a high casting temperature, blowholes will result. Because of the high shrinkage the castings are liable to develop fractures. Because of the combined carbon sulphury iron produces a deep chill. In consequence of blowholes, segregation and fusible sulphide, which produces intercrystalline weakness, sulphur tends to diminish the strength of cast-iron. The presence of sulphur tends to diminish the total carbon, but as the quantity of sulphur present in cast-iron is usually small, this may be considered negligible.

Influence of Phosphorus.—Phosphorus in pig iron exists as a phosphide, having the composition Fe_3P, which is equal to 15·6 per cent. of phosphorus. Phosphorus in pig iron has little direct influence on the condition of the carbon, but it lowers the percentage of total carbon, and this effect increases proportionately with increase of phosphorus. The amount of carbon in cast-iron with 2 per cent. of phosphorus is not much more than 2 per cent., so that as regards carbon the metal is more like high carbon steel than cast-iron. Now the more steel-like the metal is, the less is the tendency to form graphite and the greater the tendency to form combined carbon. In this respect phosphorus acts indirectly towards the formation of combined carbon.

Both the phosphide and the carbide of iron are intensely hard, but Stead considers the carbide the harder of the two. On heating cast-iron containing phosphorus to 900° C., and cooling moderately rapidly, the phosphide passes into solid solution and is distributed between the pearlite grains. Phosphorus increases the fluidity of cast-iron and renders the metal suitable for fine castings. With much phosphorus present the phosphide formed remains fluid after the general mass has solidified, and, being distributed through the metal, makes the casting more brittle and more easily fractured by shock. The ready fusibility of the phosphide eutectic renders phosphoric irons unsuitable where the iron has to resist high temperatures, as in the case of moulds and fire bars. Probably no other element weakens iron to same extent as phosphorus does, especially when present in large quantity. A moderate amount of phosphorus, while increasing the fluidity, also, according to Keep, lessens the shrinkage.

The influence of phosphorus on cast-iron may be briefly summarised as follows :—

It makes the metal harder, whiter, more fusible, weaker, more highly crystalline, prevents blowholes, and lessens the shrinkage.

Now while the effect of each element on cast-iron, when present alone, has a specific influence, some elements have directly opposing tendencies, and in certain proportions exactly neutralise each other, as for example, silicon and manganese. But there are two other most important influences which play a conspicuous part in forming the structure and therefore in modifying the properties of cast-iron, namely, time and temperature, as already indicated. The temperature of casting and the length of time the metal is allowed to remain in a certain range of high temperature are probably the most powerful agencies in determining the structure and nature of cast-iron.

In the foregoing statements the influence of silicon, manganese, sulphur, and phosphorus on highly carburised iron, when each of these elements is present alone, has been chiefly discussed, but the object of the present research was to ascertain the combined influence of two elements when simultaneously present in highly carburised iron. The mode of procedure was the same as already explained, and care was exercised to obtain alloys as free as possible from elements other than those under consideration.

Each alloy was made to contain only two elements in addition to iron and carbon, and each may be considered as pure with regard to the specific elements introduced. Each series contains the constituents in three different proportions, so as to give each in its turn a dominant, an equal and a subordinate influence as regards the quantity present. The following percentages in the accompanying ratios were taken:—2 : 2, 2 : 1, 1 : 2.

Manganese and Silicon.—A weighed quantity of pure cast-iron was embedded in charcoal in a carbon crucible and manganese and silicon added so as to yield a cast-iron containing 2 per cent. of manganese and 2 per cent. of silicon. The whole was then melted in a furnace and kept for an hour in a fused state, so as to enable the alloy, if possible, to take up additional carbon. The whole was then transferred to a muffle furnace and maintained at a temperature of about 1,100°C. for several hours in order to facilitate any separation of carbon in the form of graphite, in accordance with the views already expressed with regard to the influence of time and temperature, that is; if cast-iron, which in the liquid state contains carbon wholly in solution, is kept for a sufficient time somewhat below a temperature of 1,130°C., the carbon, in the absence of interfering elements, will separate out of solution in the form of graphite in large flaky crystals. It has also been stated that silicon, if it does not facililate the separation of graphite, does not prevent such separation. On the other hand, manganese acts as a check on such separation, so that it may be safely assumed that these two elements, silicon and manganese, tend to neutralise each other, and it is only a question of the proportion of each requisite for neutralisation. With the above percentages the silicon more than neutralises the effect of the manganese. If the whole of the manganese is chemically united with the silicon to form the compound Mn.Si., the proportion of each would be about 2 : 1, leaving an excess of silicon to unite with the iron.

Fig. 1, shows the microstructure of the alloy with 2 per cent of manganese and 2 per cent. of silicon. The graphite has separated in moderately large flakes and the iron matrix contains some free carbide of iron, or the double carbide of iron and manganese, but the main mass of the matrix is iron with possibly some manganese in solid solution, forming a structureless mass.

Another sample of cast-iron was prepared so as to contain 2 per cent. of manganese and 1 per cent. of silicon. The same conditions as before were strictly adhered to, in order to make the results precisely comparable. The result is shown in the micro-section, Fig 2. It will be observed here that while a portion of the manganese is neutralised by the silicon, there is a certain proportion of free carbide. The flakes of graphite are smaller in quantity and less in size. Evidently there has been a strong contention between the tendency of manganese to keep the carbon in solution and that of silicon, added to the influence of time and temperature, in inducing the separation of graphite. Much of the matrix is structureless, and probably contains the excess of manganese in solid solution. Now while at the temperature of the experiment graphite separated out it only required a moderately rapid lowering of the temperature below the graphite-forming range for the carbon to be kept in solution, that is, for the manganese to play its natural role.

Another alloy was prepared under precisely the same conditions as in the other cases, in the proportion of 1 per cent. of manganese, and 2 per cent. of silicon, with the result shown in Fig 3. It will be obserned that the flakes of graphite are very large and occupy a considerable portion of the surface. The matrix is largely structureless, and there is an absence of free cementite. Assuming as before that the manganese is wholly combined with the silicon to form the compound Mn Si., there would be no free manganese to unite with the iron, or to combine with the carbon to form carbide, therefore the excess of silicon would combine with the iron, leaving the carbon free and unrestrained to separate out as graphite at the temperature of the experiment.

These three experiments go to prove that manganese and silicon in cast-iron tend to neutralise each other. They form strong presumptive evidence of the union of manganese with silicon in the proportion of 55 to 28 forming the compound Mn Si., for if a higher proportion of silicon than this united with manganese there could be no free cementite in the alloys shown in Figs. 1 and 2. On the other hand, if a slower silicide were formed, the matrix of Fig 3 would not be likely to be structureless. It follows from these conclusions that 28 parts of silicon will neutralise 55 parts of manganese, which is nearly in the proportion of 1 to 2. But in the case of No. 1, although there is an excess of silicon, it has not prevented some hard structureless constituent being separated from the matrix, which may be silicide of manganese.

Manganese and Phosphorus.—Three samples of pure cast-iron were next prepared, and manganese and phosphorus added in the proportions ot 2 : 2, 2 : 1, and 1 : 2, as in the case of silicon and manganese. The conditions *of preparation* and mode of heating and cooling were the same as in the previous alloys. The phosphorus was obtained from a specially prepared rich alloy of iron and phosphorus.

The alloy with 2 per cent. manganese and 2 per cent. of phosphorus is not uniform in composition, the three chief components being irregularly distributed, namely, pearlite cementite and phosphorus eutectic. The different components are very clearly shown by submitting the section to the method of heat tinting. This consists of exposing the metal to a temperature sufficient to bring out the temper colours or oxidation films. The pearlite is seen to partake of a deeper hue than the cementite or the phosphorus eutectic.

In Fig. 4 the light wavy portion is probably a double carbide of iron and manganese, having the formula $(Fe\,Mn)_3\,C$. The darker net-like masses contain most of the phosphorus in the form of a eutectic mixture and the dark groundwork is pearlite. In addition to the above-mentioned constituents there are a few small flakes of graphite running through the pearlite areas. The manganese has very largely prevented the separation of carbon as graphite, and therefore the carbon has remained partly in solution in the iron and partly in combination with the iron, or iron and manganese, as cementite. The phosphorus has combined with the iron to form a phosphide, which is hard, white, and moderately fusible, so that it remains liquid after the general mass has solidified, and the phosphorus eutectic is the last component to solidify. This circumstance, together with its unequal distribution and the innate brittleness of the phosphide Fe_3P., readily accounts for the brittleness of phosphoric cast-iron.

Another sample of cast-iron was prepared, Fig. 5, containing 2 per cent. of manganese and 1 per cent. of phosphorus. The structure is somewhat similar to the preceding one, but the amount of phosphorus eutectic is less; the pearlite is also in quantity and the amount of structureless cementite is much more pronounced. This indicates a harder iron. Graphite in the form of flakes is absent. The cementite is probably a double carbide of iron and manganese, since there is no free iron to dissolve the manganese and form a solid solution.

A third sample was next prepared, containing 1 per cent. of manganese and 2 per cent. of phosphrous. This alloy differs considerably from the preceding ones in containing a large proportion of graphite and in the absence of plates of structureless cementite. The phosphorous eutectic occupies a large part of the surface, surrounding areas of pearlite, and running through the pearlite are flakes of graphite. The manganese must be largely in the pearlite, which therefore consists of ferrite from which the graphite has separated, and cementite, made up of the double carbide of iron and manganese. A micro-section of this alloy is shown in Fig. 6.

According to Stead, who is perhaps the greatest authority on the action of phosphorus on iron, phosphorus does not influence the condition of carbon, either to cause it to separate as graphite or to keep it in the combined form; while manganese has a very decided influence in preventing the separation of carbon as graphite. If, then, phosphorus is neutral in its action, the manganese present must tend to prevent the formation of graphite. But in the present alloy a fair proportion of graphite is in evidence, therefore 1 per cent. of manganese is insufficient to prevent some graphite separating out, and this is due to the influence of the long-sustained high temperature at which the alloy was kept. It should be stated that the graphite is segregated in certain parts, while the greater portion of the metal is free from graphite. This will be readily seen by reference to Fig. 6.

Manganese and Sulphur.—Both manganese and sulphur act in the same way as regards their influence on the condition of carbon on cast-iron, and when each element is separately present the carbon tends to remain in the combined form, the separation of graphite being prevented. Manganese itself combines with carbon and increases the quantity of total carbon the iron is capable of retaining. Sulphur also unites with the oxygen of the air to form sulphur dioxide when the air has access to the metal, so that the sulphur is partly removed by volatilisation, and causes the metal to present a honeycombed structure, due to blowholes. But sulphur also unites with the iron to form sulphide of iron, and may then be retained as a solid substance. This sulphide of iron is unstable at high temperatures. and the liberated sulphur tends to escape as a gaseous compound. But much of the sulphur is retained and assists in keeping the carbon in the combined form.

With the simultaneous presence of manganese and sulphur the latter combines with the manganese in preference to the iron, and as this manganese sulphide has a high melting and high dissociation point, the sulphur is not liberated in the gaseous form and blowholes and red-shortness are largely prevented. In cast-iron containing sulphur and manganese we may have both sulphide of iron and sulphide of manganese present, the former of which induces the retention of combined carbon while the latter seems to be largely neutral, hence we have the anomaly of two elements present in cast-iron each of which separately induces combined carbon, but when combined have practically no influence on the condition of the carbon, so that the influence of time and temperature can play their accustomed role.

Now as the melting point of sulphide of manganese, as proved by Chatelier, is superior to that of iron and very much superior to that of sulphide of iron, it follows that in a cooling liquid mass of cast-iron the sulphide of manganese is the first to crystallise out, leaving the iron and carbon free to assume their accustomed forms, hence the favourable action of manganese or iron containing sulphur. The hurtful influence of sulphide of iron is due, on the contrary, to the fact that, being the constituent to solidify last, it segregates between the grains and thus breaks the continuity of the mass.

Three samples of cast-iron with manganese and sulphur were prepared in the same proportions as in the previous experiments. Fig. 7 is the alloy made to contain 2 per cent. of manganese and 2 per cent. of sulphur. The dark portions show the sulphide of manganese forming the larger patches and the flakes of graphite the smaller and lighter ones. The lighter portion consists of pearlite with a little free cementite. The alloy with 2 per cent. of manganese and 1 per cent. of sulphur (Fig. 8) contains manganese in excess, but the structure is much the same as the preceding one, the manganese sulphide being more pronounced. Fig. 9 contains 1 per cent. of manganese and 2 per cent. of sulphur, so that the sulphur is in considerable excess. The manganese sulphipe is distributed in patches over the surface, but there is no graphite visible and analysis showed its absence. The structure consists mainly of pearlite having well-defined boundaries of cementite and some needle-shaped grains of cementite striking across the pearlite. There are also frequent blowholes, showing the influence of decomposed sulphide of iron.

The above three alloys were made to contain the proportions mentioned, but some sulphur volatilised, and the result of analyses for 7 and 9 gave 1·53 and 1·43 per cent., while that of 8 showed no loss.

Silicon and Sulphur.—It has been explained in an earlier part of this paper that silicon tends to the separation of graphite from cast-iron, while the influence of sulphur is in the opposite direction, indicating what is termed combined carbon. But silicon and sulphur may unite to form the compound $Si.S_2$, in the form of white needle-shaped crystals, which may be volatilised in a stream of gas, so that gaseous compounds of sulphur may remove both silicon and sulphur. The effect of sulphur is much more powerful than that of silicon, so that in these alloys very little graphite might be expected to be formed, and such is really the case. The structure is very confused, and in each case it is difficult to get more than a small area free from blowholes. As the effect of sulphur is to produce combined carbon, we should naturally expect to get a quantity of cementite. The constituents, therefore, appear to be cementite, pearlite, sulphide of iron, and a little graphite. All these are mixed together without any definite arrangement and interspersed with frequent blowholes.

Three alloys were made in the same proportions as in the former alloys, but in each case some of the sulphur must have passed off in the gaseous form. Fig. 10 was made to contain 2 per cent. of silicon and 2 per cent. of sulphur. The structure is very fine, containing pearlite, some massive cementite, some patches of sulphide of iron and many blowholes. Graphite is also present but in a very divided state. The alloy containing 2 per cent. of silicon and 1 per cent. of sulphur is similar to the preceding alloy, but the pearlite is well developed and the metal is full of blowholes as shown in Fig. 11. The sample with 1 per cent. of silicon and 2 per cent. of sulphur is whiter, harder, and contains much more massive cementite. It is full of blowholes, as shown in Fig. 12. Pearlite is also well developed. Here the influence of the high soaking temperature and slow cooling in allowing the graphite to separate out is counterbalanced by the influence of sulphur, and while some graphite is present it is in a too fine state of division to be evident in the micro-section. Analysis showed no diminution in the sulphur, but this may be due to the difficulty of obtaining an average sample owing to the unequal distribution of the sulphide.

Phosphorus and Silicon.—Alloys containing these elements in three different proportions were prepared in the same way as in the other alloys. Phosphorus does not appear to have any strong tendency to modify the condition of the carbon in cast-iron, while silicon probably has an influence in preventing supercooling and thus promotes the stable condition, that is, it lowers the temperature at which graphite can be separated. Here then we have two elements, one of which can be considered neutral and the other active with regard to the separation of graphite. Hence the effect of time and temperature can come fully into play, and the carbon, since it does not combine with the silicon or the phosphorus, both of which are united with the iron, can separate out as graphite under the right conditions of time and temperature. The phosphorus combines with the iron to form a hard and brittle phosphide, which is white in colour and has a comparatively low melting point. It also lowers the amount of total carbon in the iron. On the other hand the silicon combines with the iron and does not seriously harden it or make it brittle unless when present in larger quantity than in the case of these experiments. This silicon-iron alloy has a high melting point. It follows from this that the silicon-iron alloy is the first constituent to solidify when the iron is cooled down from the liquid state, leaving the phosphide of iron still fluid. This phosphide solidifies last and forms a complex eutectic mixture with the iron and carbide. The fractured surface of cast-iron containing silicon and phosphorus when slowly cooled is mottled, because of the mixture of crystals of eutectic – iron and graphite. Owing to the power of phosphorus to reduce the amount of total carbon the quantity of graphite will be limited.

Fig 13 shows the alloy containing 2 per cent. of silicon and 2 per cent. of phosphorus. There is little free ferrite the matrix being chiefly pearlite. The grapite in some parts is in the midst of a mass of ferrite and in others in the pearlite. The phosphorus eutectic is fairly regularly distributed through the mass, The alloy with 2 per cent. of silicon and 1 per cent. of phosphorus is shown in Fig. 14. It differs from Fig. 13 in the much greater portion cf ferrite and graphite, the smaller proportion of phosphorus eutectic and the small proportion of pearlite. The quantity of total carbon is greater and the smaller proportion of phosphorus has evidently reduced the quantity of cementite, hence the small quantity of pearlite. This would indicate that phosphorus has a tendeney to cause carbon to remain in the combined form, but the strength of this tendency is somewhat feeble.

A third alloy was made to contain 1 per cent. of silicon and 2 per cent of phosphorus. In this case only three constituents appear to be present. There is no free ferrite. The matrix is all pearlite and the graphite is found in the pearlite. The phosphorus eutectic is very abundant and in large masses as shown in Fig. 15.

Phosphorus and Sulphur.—Cast-iron containing phosphorus and sulphur was prepared in the same way as in the preceding alloys and the same precautions taken as regards temperature and mode of cooling. The effect of phosphorus on the condition of the carbon has been fully discussed in connection with the previous alloys, and the same remarks apply to sulphur. The influence of both elements in the present alloys is strongly marked, and the particular structure induced by each is clearly indicated in the micro-structure. The cast-iron is white, hard, brittle, and friable. It is difficult to conceive what possible use could be made of such iron in the foundry unless it be the ease with which a pig could be broken and crushed. The carbon is entirely in the combined form, and there is no trace of graphite. The phosphorus eutectic is arranged parallel with bands of structureless cementite. The matrix is composed of well-formed pearlite, but one cannot explain how ferrite could exist in pearlite in such alloys as these.

Fig. 16 is the alloy made to contain 2 per cent. of phosphorus and 2 per cent. of sulphur. Blowholes are abundant, both large and small. Wide bands of cementite occur in all parts, and in each case the phosphorus compound is arranged parallel with it, having its usual net-like structure. The matrix is made up of well-developed pearlite.

The alloy with 2 per cent. of phosphorus and 1 per cent of sulphur has practically the same structure as the preceding, but the phosphorus eutectic is in much greater quantity. Fig. 17.

The alloy with 1 per cent. of phosphorus and 2 per cent. of sulphur, Fig. 18, has also the same general structure, but the massive structureless cementite is very abundant,and the phosphorus eutectic less in quantity.

On analysis the sulphur in the 2 per cent. alloy was found to have lost 0·18 per cent. and in the one per cent. alloy 0·2 per cent.

A discussion followed in which the President, Messrs. J. W. Hall, W. J. Foster, G. H. Gibbs, and J. E. Fletcher took part, and to whom Mr. Hiorns replied.

On the proposition of the President, seconded by Mr. James Piper, a vote of thanks was given to Mr. Hiorns for his paper.

The Third Meeting of the Session was held at The Institute, Dudley, on Saturday, the 15th December, 1906.

The PRESIDENT (Mr. WILLIAM SOMERS) presided over a large attendance.

The minutes of the previous Meeting were read, approved, and signed.

Messrs. E. J. Attwood, H. H. Cooke, C. Fell, J. Ernst Fletcher, D. J. Guyatt, Richard Keeling, C. F. Mace, E. Mortimer Scott, W. Wesson, and Geo. Whitehouse were elected members of the Institute.

Mr. CHARLES H. WALL read the following paper, which was illustrated by a large number of lantern slides, drawings, and diagrams :—

THE USE OF GAS FOR HEATING AND RE-HEATING PURPOSES.

By CHARLES H. WALL, M.I.M.E.

The subject which I am dealing with in the present paper covers a very wide field, both for inquiry and application, and to enable me to keep within reasonable limits I propose to deal more with the general principles underlying such application in preference to merely giving a record of facts which may appear disconnected in themselves. As I am here also dealing with the use of gas for heating, I propose to treat of the various designs of generating plant from a general standpoint, rather than to enter into their merits in detail, which is a matter of interest chiefly to the specialist.

The Theory of Gas Production.

There is no more common object than the ordinary domestic fire, and yet none can illustrate or convey a greater variety of interesting lessons in science, both scientific and historical—such as how and when in ancient times man first became possessed of it, and the source from which he obtained it. But what is of more value in these days of practical application is a positive statement founded on the nature of things from observation and experiment, as illustrated in most of the lessons of combustion.

We can see in it the production of flame from the gases, which are produced by distillation of the coal by the action of heat burning in contact with the air. Here we have the glowing coke or carbon, which is also consumed, burning in union with the air but without flame.

When the fire is deep or thick, and contains only glowing carbon, a short bluish flame appears from its surface This is due to the fact that the carbonic acid gas, which is produced by complete combustion of the carbon in the lower strata of the fuel, becomes reduced to carbonic oxide by contact with the hot carbon during its passage through the fire. The flame is that of carbonic oxide gas burning again to carbonic acid. What passes up the chimney in this case is a mixture of carbonic acid, water vapour, nitrogen, and the excess of air passing over the fire.

When fresh fuel or coal is laid on a hot fire an immediate cooling takes place. The cold fuel takes up a certain amount of heat, if wet still more, and soon begins to give off in abundance gases of grey or yellow tint. As the heat increases, streams of flame shoot up until all the gases rising from the coal take fire and the whole of the upper surface of the fuel is covered with flame. The gases in this case are completely burned to carbonic acid and water vapour.

The gases first given off are prevented from burning by the temperature at that spot being too low to cause them to ignite, and by the further action of cold air, which meets them in large quantities, causing an alteration in their chemical composition by ts cooling effect.

If we were to enclose the upper part of the fireplace and thus stop the free passage of air to these gases, a large quantity of them would remain combustible, and with suitable arrangements could be ignited and consumed with flame. The same would happen to the carbonic oxide given off from the fire in its glowing condition. So that it is possible to change the form of the fuel into combustible gases which can be, by means of pipes or flues, carried and conveyed into places arranged for the operation and there burned.

This method of gasification, of course, consumes some of the heat of the fuel, but the process of gasification in an open fire does so also. The method of gas production nevertheless possesses many conveniences and economies in the application of heat where it is wanted.

In the ordinary open fire-grate, common to dwelling-houses, about one-eighth of the heat given off from the coal is utilised. This small proportion of the total heat of the coal shows the effects of distillation with an excess of air over the quantity actually required to burn the fuel. In coal-fired furnaces all the heat carried away by the products of combustion is not altogether lost, because the walls of the furnace take up a certain amount of heat from the hot gases in their passage through the furnace to the chimney. Nevertheless, the loss of heat from excess of air is undoubted.and there is moreover a further loss from the fact that the fireplace must be far hotter than the body of the furnace, so that the heat of the fuel is not applied in the most advantageous or best way.

These, although elementary, remarks may be useful as illustrating in a simple way some of the primary principles connected with the action of gas producers, as compared with fireplaces for solid fuel. In fact, a gas producer is an enclosed fireplace in which the fuel is partially burned, and should be made in such a way so as to produce the largest amount of combustible gas, and therefore to obtain the smallest amount of heat in the place where the solid fuel is consumed that will produce the desired effect. Varieties in the apparatus for, and the methods of carrying out the process, will be noticed later. To the general idea of working the gas producer, a few sentences may here be added.

The idea of producing fuel from combustible gases, to be burned independently, was suggested by observing the process going on during *combustion. First* the gases escaping from the heaps in which charcoal was being made, and then from blast furnaces the waste gases were found to be combustible, and were used in a variety of ways as fuel. From that point came the idea of designing and constructing an apparatus which was to be used exclusively as a medium for the production of these combustible gases.

We first find mention of the use of waste gases from 1801 to about 1837. Gas producers of a practical kind date from 1839, and in a number of forms were used in Germany, Sweden, and France for some years before the introduction of the Siemens producer into Britain in 1861. Some English inventors, however, foresaw the coming improvement; one of these, according to the late Dr. Percy, took out, in 1832, a patent for the utilisation of the waste heat of blast furnaces, and another one, Moses Pole, who mentions in his patent, 1841, a gas producer founded on the pattern of a blast furnace. Since that time a large number of designs of various forms have been introduced, but latterly the tendency has been a return to the blast furnace shape with necessary modifications.

Introduction of the Gas Producer Apparatus.

The first separate producer, that of Bischof, was designed to work with natural draught. It was cylindrical in shape with the appearance of a vertical boiler, and had grate bars and an ashpit which was closed by a door having a small opening for the admission of air. No blast being used, this producer depended for its working upon ordinary means of inducing a current through it, such as the draught from the chimney of the furnace to which it was attached.

The next example of which we have record was that of Ebelman; this was in direct contrast with Bischof, it being built upon the model of a blast furnace with solid hearth on which the fuel rested (without of course any grate bars) and blast supplied through tuyeres round the bottom part. The inside form was similar to a blast furnace, with an iron hopper projecting some distance down the throat, around which was a space for the gases to collect, and from which they were forced or passed by a branch pipe. The ash was removed by being fused or tapped as slag.

The next design we have was introduced, though in another country, by Ekman in Sweden about a year or two after Ebelman; this was distinguished from its predecessors by some original features. It was cylindrical in shape and worked by blast. the air was first warmed by being passed into a casing surrounding a portion of the body of the producer, and then passed into the fuel space by two rows of tuyeres placed nearly half way up the producer. A solid hearth was employed; the exit opening for the gases was at the bottom of the producer, which therefore worked on the downward draught principle, and was opposite the door for removing the ashes.

After that the first water-jacketed producer was introduced in France. Its shape was like an enlarged locomotive fire box, with a hopper feeding the fuel down through the crown and steam space and a large tube in place of the numerous tubes by which the gas escaped. It had grate bars and a large ashpit into which the blast for air was blown. This producer was worked by a fan and was capable of raising a considerable quantity of steam from the water-jacket forming its walls, besides supplying gas to fire another boiler.

After this came the familiar Siemens producer which was oblong or square in plan, with the back wall vertical and the front sloping inwards from near the top and terminating at inclined bars. This producer was usually placed below ground level, the feeding hoppers on the top being at ground level. The gas was conveyed by an upright tube rising from the back and then continuing horizontally; this had the effect of cooling the gas, thus increasing its density, and induced a flow or slight pressure towards the furnace. The patents for the Siemens regenerative furnace gave such control over the most economical means of using gas in furnaces that for many years nothing was done in Britain to improve the form of gas producers.

France and Germany, however, tried improved forms, some with grate and some with solid hearths, in the latter case the ash being removed by fusion as in Ebelman's producer. Details of producer designs up to the year 1885 will be found in Vol. LXXXIV. of the "Proceedings of the Institute of Civil Engineers."

At that time the forms most in use after the Siemens design were, in Britain, those of Gormans. Wilson, and Dowson. In America, Phillips' design. In France, Minary's, Ponsard and Lurman, Haupt, Liegal, Schilling and others.

Since then the tendency has been towards continuous working in the case of producers used for furnaces, and towards the recovery of ammonia and the production of gas from coal suitable for use in engines where large installations are possible. We have water bottoms applied in different forms which allow ashes to be removed from time to time or continuously without stopping the production of gas, and we have systems of gas cooling and washing carried out for the purification of the gas.

We may enumerate some of the most modern producers such as those of Dawson, Duff, Mond, Dowson, Thwaite, Pinkney, and one of the latest, the Duff-Whitfield. There are of course other producers in existence, but the tendency is towards the employment of one or two of the most recent forms. A good producer must have the greatest simplicity of design with a minimum of first cost and be of maximum durability. It should be easy to work, and all the various parts should be accessible for repair, able to use any quality of fuel without trouble, and produce he best quality of gas obtainable from it. The air admitted should be fed through the fuel in such a way that combustion is conducted through the mass evenly, so that no free oxygen can escape to burn the gases when formed in the upper part of the producer It must work regularly and continuously as to gas-making and have the least number of joints or working parts, which means that less attention will be required. The formation of clinker must be reduced to a minimum so that labour and repairs may be kept at the lowest point.

If the producer and the combustion are properly arranged the loss by radiation should be very small. The steam supply required for working is usually decided by the purpose to which the gas is to be applied.

The Gaseous Fuel of the Producers practically considered.

In the case of producers supplying gas direct to furnaces without any separation of the various qualities of gas yielded at different times in the producer, or without any treatment of the total gas for the recovery of ammonia, or for the removal of tar, dust, or soot, it is usual to have the air blast supplied by an induced current due to a jet of steam admitted into the narrow neck of a tapered trumpet-shaped pipe. The delivery of the air and steam inside the producer has been arranged in different ways in various producers, and the position of this inlet has some influence on the composition of the resulting gas. The best position is undoubtedly the centre of the mass of fuel and as near the bottom of the producer as is consistent with the arrangement for cleaning out the ashes, because this not only ensures the passage of the air through the fuel, but also that its oxygen will be combined with the carbon, and that none will pass to the surface in a free state, thus causing loss by the gas burning on the surface.

If air is admitted at the sides of the producer it is easy for some portions to find their way up between the fuel and producer wall or lining, and so ignite the gases at the surface of the fuel.

Some producers have been worked with an air blast alone, the result of which is a higher temperature in the zone of combustion, and almost a total absence of hydrogen and hydro carbons from the gas, which causes an excess of clinker to form in the producer.

The introduction of steam has the effect of lowering the temperature of combustion, and so protecting the producer from corrosive action, whilst by the decomposition of the steam (in addition to its regulating the temperature) hydrogen is added to the gases, and the lower temperature saves some of the volatile hydro-carbons from being decomposed. The percentage of carbonic acid (carbon dioxide) is increased, and that of carbonic oxide (carbon monoxide) is often decreased. If the quantity of steam used is in excess, the resulting gas contains more carbon dioxide and hydrogen, though less nitrogen in proportion. To obtain the ammonia from the gases, the combustion of the coke, or fixed carbon of the coal in the producer, must be conducted at a low temperature by the admission of a large excess of steam, or of hydrogen, in such a form as to provide both for the combination with the nitrogen contained in the coke, and for preservation of the ammonia when formed.

The following are some representative examples of the quality of gas made in different producers.

Ebelman producer :—Using wood charcoal as fuel (1) with dry air blast, and (2) with air and steam.

	Carbon monoxide. CO	Hydrogen H	Hydro carbon. CH_4 etc.	Oxygen O	Carbon dioxide. CO_2	Nitrogen N
(1)	33·3	2·8	—	—	0·5	63·4
(2)	27·2	14·0	—	—	5·5	53·3

The next two are from Siemens sloping grate producers, using coal (3) working by ordinary draught, and (4) with ashpit closed and steam jet air blast :—

	CO	H	CH_4 etc.	O	CO_2	N
(3)	25·6	—	4·4	—	4·3	65·7
(4)	24·4	8·6	2·4	—	5·2	59·4

The two next are average samples of gas from Wilson producers, with steam jet blast (5) using Durham coal, and (6) using fine Yorkshire slack :—

	CO	H	CH_4 etc.	O	CO_2	N
(5)	26·89	11·55	1·45	—	4·0	56·11
(6)	23·41	13·82	2·22	—	4·69	55·86

The two following are from a Phillips producer (7) working with fan blast, and (8) working with steam blast :—

	CO	H	CH_4 etc.	O	CO_2	N
(7)	27·31	—	1·4	—	3·9	67·4
(8)	20·0	8·7	1·2	—	8·7	61·4

The next is an analysis of gas made in a Dowson producer, using superheated steam and induced air blast, and working with Garrant anthracite.

	CO	H	CH_4 etc.	O	CO_2	N
(9)	25·07	18·73	0·62	0·03	6·57	48·98

This analysis was made by the late William Foster, and shows evidence of his usual care and thoroughness.

Finally, we have two analyses of gas in which coal was being treated in a gas producer, with excess of steam, in order to secure the nitrogen of the coke as ammonia in the gases (10) is an analysis of the gas actually made, and (11) is a corrected analysis showing what a lessened proportion of air to steam would produce :—

	CO	H	CH_4 etc.	O	CO_2	N
(10)	8·1	28·6	2·3	—	16·6	44·4
(11)	10·72	37·19	—	—	21·32	30·77

The resemblance between (10) and a specimen of gas from Mond producers is shown by the following analysis of Mond producer-gas, as given by Mr. H. A. Humphrey in his paper on the subject:—

	CO	H	CH_4 etc.	O	CO_2	N
(12)	10·0	26·0	2·5	—	16·0	43·8

This specimen of gas was taken from Dr. Mond's producers when being worked with a large excess of steam for the recovery of ammonia from the gas. It corresponds with an analysis of gas from the Duff producer plant when worked under similar conditions with good slack, as the following shows:—

	CO	H	CH_4 etc.	O	CO_2	N
(13)	11·0	28·0	2·5	—	15·5	43·0

It will be understood that by sacrificing the yield of ammonia the quality of the gas can always be improved for heating purposes. The following is an average of daily analyses ranging over a period of several weeks, the gas having been made in a Duff producer for heating gas:—

	CO	H	CH_4 etc.	O	CO_2	N
(14)	26·8	13·4	4·4	—	4·0	51·4

In all these analyses the figures in the first three columns, added together, give the percentage of combustible material in the produce gas, and those of the last two columns give the non-combustible elements. The average combustible material varies from 30 to 45 per cent., and from 50 to 70 per cent. non-combustible. Those worked with steam blast have the advantage, as Nos. 2, 4, 5, 6, 8, and 14 demonstrate. The gas produced as per 10, 12, and 13 show about 38 combustible and 61 per cent. incombustible. In this case the combustible ingredients have, theoretically, a comparatively high calorific power. The gas as it comes from the producers is not suitable for furnaces owing to the presence of a large volume of undecomposed steam which must be removed by cooling or washing before the heat value of the gas can be realised. It is only in installations where cooling and scrubbing appliances are used that gas is produced in such a way that the ammonia from the nitrogen of the fuel can be recovered. As regards the calorific value of producer gas, without going into figures with regard to its amount, it stands to reason that in its production from the coal the amount of heat available in the gas must be less than in the original coal by the quantity which has become lost in the process of making the solid fuel into the gaseous form, and the loss also due to the production and decomposition of the small quantity of steam used for the blast. The actual loss as a rule does not exceed from 9 to 12½ per cent. of the heat of the original solid fuel.

After all, it is not strictly a loss, for the same process in the case of a coal-fired furnace must go on, because the fuel must be turned into gas before the existence of a flame is possible.

The great secret of the success of gas firing—and there can be no question about it—is due to the fact that it does away with the intermittent series of heating and partially cooling actions which are unavoidable in coal-fire furnaces, and substitutes for them that direct contact of flame with the heating surfaces which gives a constant and steady application of the temperature desired.

The necessary charging of fuel and breaking up the fire or clinkering the grate bars of a coal-fed fire cause cooling periods, due to the quantity of the charges which are at times heavy and at other times light, which require at these different states different quantities of air, but which is almost never supplied, which means a fluctuation of temperature. The greatest heat of the fuel is in the fire-place, where it is not wanted, instead of in the body of the furnace, where it is wanted. This is one of the adverse features of solid fuel firing. Another inconvenience and source of loss is the presence of uncombined oxygen due to the excess of air which cannot be prevented, thus causing oxidition and waste of the furnace contents, and the presence of ashes and dust carried over by the draught of the fire.

The balance in favour of gas firing would assert itself even if the full consumption was the same in both methods, if it only got rid of the above-named drawbacks which arise from coal-fired furnaces. In the case of furnaces requiring the highest temperature—for such purposes as melting steel—gas firing has no equal. It is safe to say it would be practically impossible to work without gaseous fuel.

Gas firing starts with the advantage of being capable of using the cheaper kinds of slack and small coal which will give any required degree of heat. Other sources of saving, and advantages claimed for gas firing, are the command and supply of the air required for combustion, so that the quantity above the chemical requirements is reduced to a minimum, the production of heat at the proper place in the furnace where it is wanted, the saving of waste heat in the spent gases by means of continuous or reversing regeneration. By bringing the air and the gas to about the same temperature before ignition, the greatest rapidity of combustion can be secured and a temperature of any desired degree maintained. By means of valves the quantity of air and gas can so be regulated that oxidation of the furnace contents may be prevented, besides a reducing or non-oxidising atmosphere may even be maintained in the furnace. Dust and ashes are practically non-existent, and complete cleanliness of heating secured. Absence of smoke is another great consideration, and proves that we get complete combustion and thus the full use of the fuel. When we consider all these things the wonder is that the gas firing has not superseded every other method that still exists.

In boiler firing by gas, uncertainty as to being able to make a substantial saving in fuel has often prevented its adoption, and this uncertainty has been caused by not observing the first condition of the problem of economical firing. This can easily be remedied, and a hindrance to the extended usefulness of the system of firing by gas will thus be removed. Gas firing may in the near future become compulsory for industrial operations, with a view to smoke prevention in towns, and users of fuel should first consider how the system can be applied to their own particular requirements.

Producer Apparatus practically considered.

With reference to the many different requirements of heating work it is a little difficult what to select for mention, as the field for the application of gaseous fuel is a very large one. It is first necessary to exercise a good deal of judgment in each case as it appears, and to consider whether or not the installation of a gas plant is justified by all the circumstances. If any particular appliance of coal firing shows a very high thermal efficiency one has to consider whether a change would pay. There may be other reasons for consideration, such as increased convenience, cleanliness, reduced attendance, and money saved in cartage of fuel to, and ashes away from, the furnace; these are most important.

The method which gives good results in one instance may totally fail in another, and this has in some instances led to abandonment of gas firing. This need never occur if all things have been carefully considered from the outset and the heating apparatus properly designed.

A saving of from 15 per cent. to 75 per cent. may be effected by most manufacturers if the matter is considered as just described.

To the larger industrial applications of gaseous fuel, we owe a great debt to the late Sir William Siemens. The regenerative system which he introduced has quite revolutionised many of the processes carried on, and has been adapted to many types of furnaces, the heating of which has resulted in very great economies. It was also due to him that we had in this country the first practical experience of producer gas obtained by the use of the original sloping grate producer. The Siemens type of regenerative furnace has been universally adopted for steel making, whilst his first producer was not designed for working at high speed, the best results being obtained when the coal gasified equalled a rate of 13lbs. per square foot of grate area per hour. Attempts were made to increase the working of this producer by enclosing the ashpit and forcing air into it by means of a steam jet blower, but this met with little success, no doubt due to the design, which allowed only for thin fires on the sloping bars which was against a high rate of gas production.

A higher rate of working, with the advantage of having hotter gas delivered to the furnaces at a slight pressure, and without the loss of the hydro-carbons (which was considerable in the Siemens original producer due to the cooling tube) was obtained with the solid hearth producers worked with steam jet or other blast; this was called the Wilson producer, and was for some years the one most generally adopted after the Siemens. Its rate of working was from 26 to 30lbs. of slack gasified per square foot of grate area per hour, or about double the rate of work in the ordinary Siemens grate producers Another point to be considered in comparing the two producers was the relative space occupied. The Siemens 4cwt. per hour producer covered an area of 361 square feet, and the Wilson 126 square feet only. Another advantage, due to the Wilson producer being thoroughly closed, was that at any time the production of gas could be interrupted by stopping the steam jet blower and closing the valve in the down comer, and yet the action of the producer could be re-started with a few minutes delay, even after a stoppage of 36 hours. A short description of this producer may be of interest. Across the surface of the solid hearth a tuyere casting extended, this was rectangular in section up to the end of the air exit openings from it into the producer, and of a cruciform section beyond that up to the producer shell. The openings for the escape of air and steam into the producer were arranged like pigeon holes—three on each side of the tuyere casting—which, when covered by brickwork, formed a broad bridge running across the centre of the hearth. The air and steam were delivered closed to the hearth and near the centre of the producer, but being forced horizontally outwards towards the sides, the centre portion of the fuel directly above the tuyere was out of direct line of action of the blast. This, no doubt, accounted for the clinker frequently formed on the sides, and was one of the greatest drawbacks of the producer—as indeed it was to all the closed hearth type through the trouble and difficulty of cleaning and the stoppage of gas production during that operation.

The first producer, no doubt, to which a water trough was applied, was the continuous automatically cleaning producer patented by A. Wilson, in 1882. In this producer the solid hearth was replaced by a cast-iron bottom in the shape of the letter W, the blast passage being between the two V shaped channels; in the bottom of each channel a helical propeller was made to revolve at a slow speed. The result of this was that the ashes were ejected by means of screws or worms immersed in water, and were delivered up a shoot or spout into a barrow. The water in the trough formed a seal against the escape of gas or blast from the producer. It was an ingenious arrangement, but involved a greater first cost. The upkeep also was expensive, due to the number of working parts which required attention, and which were liable to get out of order; in addition a small engine was required to work it.

Then followed producers by E. Brook, and the Taylor revolving bottom producer, introduced in America. These had the same defects as the Wilson producer just described, that of too many parts, and those of a complex nature.

J. W. Shiel and Bernard Dawson both introduced producers with water sealed troughs on the same principle as the earlier ones.

The troughs extended for a certain width right across the centre of the producer, and at each end projected past the shell with a sloping bottom, from which the ash could be raked from either side of the producer from under the water. These producers had very bad features in the cast-iron conical plates, or boxes, introduced into the interior at the bottom. The Dawson design has since then been simplified, and in its latest form is quite free from the objections stated above. The producer is circular, the casing being supported by castings or standards, whilst the water trough is circular, and extends all round the producer bottom, having at the ground level a larger diameter than the producer casing. This makes it possible to remove the ashes from any part ot the circumference, The centre grate or tuyere is covered by a conical bonnet which is necessary for deflecting the descending fuel, and prevents it from entering or choking the blast pipe to which it is connected. The great advantage of this bonnet is the regular distribution of the blast from the centre ontwards, and thus makes it one of the best modern forms of the gas producer for general heating operations.

Undoubtedly the most largely used of all the recent producers is that of E. J. Duff. It is of simple design, made either circular or rectangular on plan, it is a water bottom producer and of the continuous type. The grate of this producer is one of its best features, being so constructed that an equal distribution of the blast takes place from the centre to the inside of the producer walls, thus preventing any escape of free air. The grate is in the form of the letter A and it will thus be seen if the sides are perforated the tendency of the blast is to ascend in a vertical direction. The good quality of the gas produced lies in this thorough diffusion of air and steam through the fuel, which produces those chemical changes necessary for good gas, and thus ensures complete combustion in the furnace.

The Duff-Whitfield patent gas producer is an improvement on the Duff and may be accepted as one of the best in existence.

The chief feature of this producer is found in the method of dealing with the volatile products from the coal. In producers which may be unavoidably placed some distance away from the furnace, or gasometer as the case may be, the tar vapours pass away mingled with the hot producer gas; these condense on the first contact with the colder surface of the flues, and have to be burnt out from time to time. The quantity ot this vapour is considerably reduced in this producer in the following manner :—The tarry vapours are drawn from the upper part of the fuel chamber, and injected by means of steam jets into the incandescent coke above the zone of combustion, the main outlet for the gas from the producer being placed at a lower level than is usual with other producers. The result of this is, the sensible heat produced by the combustion of the solid carbon acts so as to decompose the tarry vapour and the steam by which they are driven into the fire, this decomposition producing hydrogen and carbonic oxide without dilution with nitrogen.

The action of this producer is as follows:—The producer is filled as close up to the hopper as convenient for working, the lower portion of the fuel being raised to a temperature of incandesence the more volatile vapours are drawn off from the top through the primary circulator and injected into the highly heated portions of the lower zone. The height of fuel is kept fairly constant for obtaining uniform results. The secondary circulator draws off, at a lower level, the less volatile products and those which may have escaped the primary circulator; these also are delivered to the lower zone. The solid carbon is burned on the grate by air blast. but the hydro-carbon vapours are forced into the incandescent carbon with steam, but minus additional air, and when these are decomposed the hydrogen from the hydro-carbon and the steam passes off free, whilst the carbon of the hydro-carbon and the oxygen from the steam form carbonic oxide. For gas engines especially this producer should have large claims.

The Application of Producer Gas to Furnaces.

When coal fired furnaces were the only ones in use, prior to the introduction of gas firing, the inevitable volumes of black smoke appearing from their chimneys often suggested the thought that the man who could turn that waste of fuel into heat would make a fortune, besides conferring a great benefit to mankind.

That is what gas firing can do, but that portion of its work is often lost sight of and the furnace question is dealt with on the merely theoretical basis of the number of heat units evolved by burning so much solid carbon to carbon-dioxide compared with the amount of heat yielded by burning producer gas from the same quantity of carbon. The theory, however, fails, not only because solid carbon or coal never is perfectly burned in practice, or there would be no smoke and no cinders made, and no excess of air used, but also because even if it were burned the theoretical number of heat units produced in the grate would not necessarily be available in the furnace. Better results are possible from gas firing than could be obtained from the direct use of solid coal, providing always that the furnace is suitably designed.

It is not too much to say that the manufacture of mild steel, as it is carried on to-day, owes its existence to the regenerative furnace of Siemens, such a process as that of the open-hearth furnace being practically impossible with coal firing. Such success has, however, made people expect too much from gas furnaces, especially when the same economy has not been realised from a gas furnace which may have been applied to some other process not requiring the same degree of heat. In some operations using only moderate temperatures, it stands to reason that the saving cannot be so great. Each case should be considered on its own merits and all merits passed in review, and the matter not decided upon one or two points only to the exclusion of all others.

There are a great number and variety of designs in gas fired furnaces which we may group into fairly well defined classes :—1st, furnaces with reversing regenerators or accumulators. ; 2nd, furnaces with continuous regeneration of heat; 3rd, furnaces without heat regeneration; 4th, blow pipe furnaces, with or without heat recuperation ; 5th, kilns ; 6th, furnaces having a gas producer as part of the structure of each.

(1) The most important is undoubtedly the ordinary reversing regenerator furnace of Siemens, not only because the highest heats (excepting those of electric furnaces) are obtained in it, but also because it is the most highly organised product that human ingenuity has ever produced. The principle of heat regeneration, or accumulation of what would be lost heat, is older than Siemens, but it was to his application of it to the practical work of furnaces that such an imperishable lustre is reflected on his memory. In the reversing regenerators the same surfaces which are used to absorb and store up the heat of the gases in their passage from the furnace to the chimney are in turn, by reversing the direction of the currents, made use of to heat up the incoming gas and air prior to their union in the combustion space. There is no loss of heat by its having to be transmitted through conductors, good or bad. The rapidity of inflamation, and the temperature of the flame produced, are only limited by the durability of the materials of which the furnace may be built.

The ordinary form of Siemens furnace used for melting glass, steel, copper, or other metals, or for the heating or re-heating of iron piles, steel ingots or forgings, has its regenerative chambers beneath the furnace, and either wholly or partially sunk in the ground. Many attempts have been made to find a less costly arrangement to the underground chambers, but none can be found unless it be at a cost of less efficiency theoretically, the advantage claimed for under furnace chambers being that it is physically more correct for heat to ascend than descend, thus the heat is arrested from the waste gases on their being made to descend through the accumulators after leaving the furnace.

(2) Continuous regenerators have been made in brickwork by having continuous passages built for the passage of the hot gases in one direction, and of the air which is being warmed in the opposite direction, the German furnace being an example of one method, and the Ponsard (in France), and Radcliffe (in this country) of another, having fire brick

pipes and perforated bricks in the chambers. One of the most successful applications of continuous air regeneration is the Weardale furnace of Mr. H. W. Hollis, which is used for re-heating slabs and blooms for rolling mills, also ingots for large forgings. The design of this furnace differs from others in the fact that none of its regenerator passages are beneath the furnace bed, and that, on the contrary, the space between the double crown or roof is used for an air heating chamber. There are also passages or flues for air heating at the ends and back walls of the furnace. The air has been known to reach a temperature of from 850 to 1000 degrees Fah. in the chamber between the furnace roof arches. The gas is introduced by an opening in the furnace crown, and combustion commences even in the air heating chamber. This class of furnace is generally so arranged that the waste heat from the gases is passed through a boiler, from which steam is raised to give motive power to the mill, steam hammer, or forging press, as the case may be, and which results in this furnace being one of the most satisfactory in use. The construction of this furnace is more simple than the Siemens, and less costly. (See *Journ. Iron and Steel Inst.*, No. 1, 1897.)

(3) Furnaces without heat regeneration are generally applied to drying and evaporating operations, and are often wrongly used as in boilers for steam raising. The drying and evaporating processes include such general operations as arrangements of gas fired core stoves for foundries, brewers' coppers, and to tar and oil stills, where cleanliness is an important point combined with a steady regulation of a moderate temperature. Such a system has much to recommend it.

In the case of steam boilers, the practice of using producer gas has been too hastily formed on that of using the waste gas from blast furnaces in iron works, where economy of such fuel has not been necessary or aimed at. Nevertheless, some good results have been obtained with blast furnace waste gas when applied to boiler firing. When, however, gas producers are installed for boiler firing, it may nearly always be taken as axiomatic that preliminary heating of the air bears the same ratio to economy that compression does to the efficiency of gas engines. That is to say, that where the air is not heated by waste heat, economy in fuel should not be expected any more than efficiency in a gas engine would be where compression of the charges of gas and air is omitted. The temperature of combustion in boiler furnaces ought to be high, and the heat cannot accumulate there as it is directly abstracted from the flame by contact with the metal surface of the boiler, and yet the waste gases must leave the boiler at a temperature above that of steam, hence the necessity of heat recuperation.

(4) Blow pipe furnaces present a useful method of applying gas for heating operations, such as tempering, hardening, and brazing.

A short description of a few of the applications to which blow pipe furnaces using producer gas may be put, will not here, I hope, be out of place.

These furnaces are made especially for hardening and tempering tools, such as lathe tools, flat drills, punches, milling cutters, dies, taps, reamers, and also the wearing parts of machines, bicycle and motor car parts, or any article which will go into the furnace. They are made in various sizes, ranging in heating space 3in. by 3in. in the smaller, to 52in. by 18in. by 7½in. in the larger, six sizes in all, each furnace fire-brick lined, and fitted with adjustable burners, through which the proper proportion of air and gas for complete combustion is controlled by each burner as they are adjustable both for the air and gas at the nozzle, hence when the volume of air or gas is adjusted, no alteration of pressure takes place as is the case when the adjustment is done by means of cocks on the main pipes leading to the furnaces. Therefore these burners are more economical than any other, and no explosion can take place when lighting up. A temperature of from 2000° to 2200° F., or 1000° to 1200° C. can be maintained.

A crucible tilting gas furnace is now made by which means the life of the crucible is prolonged through non-removal from the furnace for each melting operation.

Also a furnace for heating rivets by gas. In all these furnaces there may be fitted a hot air blast apparatus (Allday's Patent) by which means the cold incoming air is heated to a high degree before it enters the furnace, thus increasing their economy, and thereby effecting a saving of gas.

(5) As specimens of the application of gas to kilns we have the fire-brick kilns of Mr. James Dunnachie, of Glenboig Fire-brick Works, and the Murray and Macintyre pottery kilns used at Rutherglen and elsewhere. Drawing No. 3987 shows the arrangement of a Weardale patent continuous gas-fired kiln. When one of the kilns has been burnt off, the air required for the combustion of the gas in the next kiln is provided by being drawn through the material cooling done and efficient air regeneration is thus obtained. The calcining of iron-ores has been carried out by gas-fired kilns.

(6) Many furnaces have been constructed and worked with a gas producer forming an integral part of the furnace, notably those of Boetius, Ponsard, and others. The new form of Siemens furnace, in its principal feature, consists in the arrangement for passing a portion of the hot waste gases into the producer instead of all being taken through the regenerators. and in the air for combustion only being heated, the producers being built in with the furnace, or near to it, the sensible heat of the gaseous fuel is now saved instead of being lost, as in the older type of Siemens Furnace with the separate producer. The cost of building the new form Siemens is thus reduced by from 30 to 50 per cent.

The extra saving in fuel over the older type amounts to as much as 30 to 40 per cent. The outlay in building one of these modern furnaces, of a medium size, has been entirely saved in twelve months working in the fuel consumption alone.

Fuel considered economically from using Gas Producers.

The quantity of fuel stored in the earth is of necessity a finite quantity. Although man so far has developed many methods of consuming or destroying these stores of fuel, up till now no process has ever been invented to replace that fuel. Statistics show the rate at which coal is being raised and consumed, but we have no records showing what coal is being wasted and what proportion could be saved if more rational methods of using it were employed.

The total output of coal for the world during the year 1899 was between 650 and 700 millions tons, the output 50 years previous to this being 50 million tons only. Of that amount America contributed 226 million tons and Great Britain 220 millions, an increase of 18 million tons on the previous year's output. Deducting the quantity exported, the home consumption of Great Britain for the above year was close upon 177 million tons. What became of it, how was it used, and how much of it was wasted? Dr. Siemens, in 1873, computed that one third of the coal raised in Great Britain was consumed in metallurgical furnaces, whilst later calculations show that this proportion is still maintained.

Dr. Siemens said, in 1873, that he estimated that "If we could make up our minds to consume our coal in a careful and judicious manner according to our present lights, we should be able to reduce the consumption by 50 per cent. This would involve a very considerable expenditure of capital and must be a work of time, but what I contend is that our progress in effecting economy ought to be accelerated in order to establish a balance between the present production and the ever-increasing demand for heat." In fact, to show the margin of improvement possible, in 1873 Dr. Siemens stated that 10 million tons of coal would give more than the equivalent of the heat energy actually required, *i.e.*, when 105 million tons were consumed, this being approximately the quantity used at that period.

From the above it will be seen what a large field is open for improved or economical appliances, amongst which the gas producer undoubtedly holds first place, and that such economies are possible it is easy to show. One pound of coal yielding 12,000 British thermal units represents 12,000 × 772 = 9,264,000 foot pounds or units of energy and it is a mere matter of division to find out that it should represent 1 horse power for 4¾ hours. Out of this possible 4¾ at present the very best steam engine gives us 1, or a loss of 3¾ hours. Similarly with metallurgical furnaces, taking the specific heat of iron at 0·114 and the welding heat at 2,900 degrees Fah. it would require ·114 × 2,900 =

331 units to heat 1lb. of iron to that point. On the previous basis of the heat value of coal this shows that 1 ton of coal should bring 36 tons of iron to the welding heat. In coal fired re-heating furnaces, as Siemens pointed out, 1 ton of coal has been used to heat up only $1\frac{2}{3}$ tons of iron or only $\frac{1}{21}$ part of the theoretical maximum.

Regarding steel, Siemens said "In melting 1 ton of steel in pots $2\frac{1}{2}$ tons of coke are consumed. Taking the melting point of steel at 3,600 degrees Fah. and the specific heat at 0·119 it takes 418 units to melt a pound of steel. Taking the heat producing power of coke also at 12,000 units 1 ton of coke ought to be able to melt 28 tons steel. The Sheffield pot steel melting furnace therefore utilizes only $\frac{1}{70}$ part of the theoretical heat developed in combustion.

Siemens claimed to melt 1 ton of steel in his furnace with 12 cwt. of small coal used in the producer, this was in his open hearth furnace. In pot steel gas furnaces 35 cwt. of small coal used in the producer per ton of steel melted is not uncommon practice. Still theoretically 1 cwt. of fuel should melt 28 cwt. of steel.

In the Weardale re-heating furnace 1·7 and 2cwt. of coal used in the producer has been sufficient per ton of slabs heated, which is a great improvement on coal firing but does not reach the theoretical possible, viz: 1 cwt. fuel to 36 cwt. of iron heated. Still it shows what gas firing is capable of doing. In industries requiring the use of kilns, such as brick-making and pottery firing, there are other economies to be considered apart from the saving of fuel, such as the shortened time for the proper burning of the bricks, much cleaner bricks and fewer repairs to kilns. In boiler firing with producer gas even with cold air, in a number of instances, a large saving in the cost of working has been accomplished by using a cheaper quality of fuel, which could be used in producers, and which would have been almost useless if burned on the boiler furnace grates.

An increased efficiency of evaporation from the same amount of surface is always obtained with gas firing, also a saving in wear and tear which means reduced repairs. These instances may be taken as types of the various applications to which producer gas lends itself as regards furnace work.

With regard to gas-fired furnaces generally, the subject is one which is always full of interest, especially so as the supply of our fuel is limited, and it behoves manufacturers to consider this question not only as a means of lessening the cost of production by the increased output gas-fired furnaces give over coal-fired, but also as a means of prolonging the commercial industry of this country, by saving fuel, and making our big manufacturing centres more healthy by freeing them from smoke and dust, which gas firing obviates, and so enabling the working classes to live in a purer atmosphere. This would mean a stronger race of men who could turn out more work than is now done under the existing circumstances.

In concluding this paper, the author desires to express his thanks to Messrs. Masons, Ltd (of Manchester), Messrs. Allday and Onions, Ltd. (Birmingham), and Messrs. Siemens (London), for the use of the lantern slides, drawings, and prints they have so kindly lent him with which this paper has been illustrated.

THE DISCUSSION.

The **President**: I am sure you will agree with me that there is no more necessary study for the South Staffordshire ironmakers of to-day than that dealt with to-night, viz., economy in works practice. We are indebted to Mr. Wall for his valuable contribution. I am pleased to learn from colliery owners and colliery engineers that the supply of coal in this district will last for many generations. The essential nature of our fuel to our manufacturers is one of the greatest arguments impelling to a careful use of it. We should all see that we get all the power we can out of our works' coal, and further, that we burn it with a due sense of economy. The paper deals with the question of the employment of gas for heating and re-heating purposes in an exhaustive manner, and we have all gained welcome information. With regard to the technical points in Mr Wall's contribution—and it bristled with them—I do not propose to express an opinion. The gas producing plant at our own works is managed by my brother. Whenever he is present, and he is to-night, I leave the discussion of technical points to him. He knows much more of these matters than I do. I trust that the debate this evening will be thorough. I am certain Mr. Wall will be pleased to answer any questions the members of the Institute like to put.

Mr. **Walter Jones**: I desire to congratulate Mr. Wall on his excellent paper. He says there that "When coal-fired furnaces were the only ones in use, the volumes of black smoke often suggested that the man who could turn the fuel waste into heat would confer a great benefit upon the community." Well, we have heard a great deal in the past about the "Black Country." It is more than time we converted it into a white, or at least a cleaner, country. At the end of his paper Mr. Wall returns to the charge again. He argues, and I think rightly, that manufacturers should favourably regard gas-fired furnaces "if only that they may make the manufacturing centres more healthy by freeing them from smoke and dust." It is my conviction that if this advantage, is to be secured it will be necessary to bring pressure to bear upon local governing authorities to insist that works proprietors and works managers, should exercise more care, and avail themselves of every appliance which has proved its worth to prevent the making of, or to secure the consumption of works' smoke. It will involve pecuniary outlay, of course, to consume your works' smoke; but the thing is largely possible of accomplishment, and I, for one, would say "Never mind the first cost, it will be money well spent in many ways." In the closing division of his paper, headed "Fuel considered economically from using gas producers," Mr. Wall goes into figures bearing upon the amouut of energy produced under varying circumstances from the combustion of coal. I want the members to analyse Mr. Wall's figures and calculations. It is very easy to talk about thermal units—nothing easier—and to divide those units or to multiply them. And it is just as easy to make serious mistakes and while apparently proving a simple sum to really become hopelessly at sea and land yourself in an absolute fog. I have made a few notes upon this portion of the paper before coming here, and had I had opportunity, it was my intention to send a copy of my notes to the author before the meeting, in order that he might have had a fair opportunity of replying. But I regret I have not been able to communicate with Mr. Wall. I have simply put in these "notes" for what they are worth I may be right, or I may be wrong; but the whole subject is such an extremely complicated and delicate one that it lends itself to very varying arguments and very varying conclusions also, according to the respective standpoints from which it is judged. What I am anxious to do, and have been anxious about for some considerable time past is, if possible, to get at the bottom of this matter. I am quite aware of the value of standards to work to, but the "British thermal unit of heat" has been a stumbling block which has hitherto proved insurmountable. I am not alone in this respect. My experience has been that of hundreds of capable engineers before me. And even at the present time I myself know scores who find the problem inscrutable. With the exception of this division of his paper, I desire in concluding my remarks to congratulate Mr. Wall on his production this evening.

I have noticed when testing the efficiency of boilers heated by gas, that the higher the water temperature, the slower is the absorption of heat, and the loss by radiation is greatly increased:—

Approximately	Fahr.	Increase.	B.T.U.
1 cubic foot of Gas will raise 10lbs. of water	50° to 110°	= 60°	= 600
1 ,, ,, ,,	110° to 160°	= 50°	= 500
1 ,, ,, ,,	160° to 190°	= 30°	= 300
1 ,, ,, ,,	190° to 212°	= 22°	= 220

Showing a loss of efficiency between 600 and 220 B.T.U. of 65 per cent. The actual heat in the gas would be about 630 B.T.U., so that when raising the water the first 60° the efficiency was excellent.

I have also noticed when boiling water with a steam jet that the efficiency is about 1,200 heat units per lb. of steam for an increase in temperature of 20° starting at 50°; but to get an increase of 12° from 200 to 212°, the efficiency is about 800 heat units instead of 1,200°, or a loss of about 50 per cent. in efficiency.

I wrote a paper this year on "Heat Losses and Heat Transmission," which was read at Chicago by Professor Kinealy before the American Institution of Heating Engineers, calling attention to the great disparity between the theoretical and the actual losses, which showed a variation of from 100 per cent. to 200 per cent. between theory and practice.

I pointed out the discrepancies between the co-efficients of American, British, and German authorities, including Professor Reitschel, of Germany, whose figures are adopted by the German Government. My paper has been re-printed in German in *Gesundheits-Ingenieur München*, and is causing considerable discussion. I found by actual tests that the B.T.U. required to give a temperature of 100° Fahr. was 600 per cent. more than would be necessary for 60° temperature; but the B.T.U. provided from theoretical calculations showed an increase of 267 per cent. only.

I have submitted similar facts and figures to heating experts in England, America, Germany, and Hungary, and up to the present have not yet obtained a satisfactory explanation of the wide discrepancies between the theoretical and the practical results. Now, if the difference between theory and practice, when dealing with temperatures of 100° to 250° only amounts to 100 per cent. or 200 per cent., we must expect these discrepancies to be still greater when degrees of temperature are thousands instead of hundreds. The point I wish to emphasise is this. If 1 B.T.U will raise 1lb. of water, or equivalent weight of metal, at 32° one degree, will the same amount of heat raise the temperature one degree, starting at 300° or at 3,000°? Mr. Wall appears to have fallen into the same error as many other engineers, that the B.T.U. has the same relative value, irrespective of the temperature or starting point. I believe the ratio of value for high temperatures will be altogether different from that required at low temperatures.

Mr. Box, in his excellent book on "Heat," table 105, page 220, says—"The Ratio of loss varies from ·94 (when the difference in the temperature of the air and the body in contact is 18°) to 1·72, when the difference in temperature is 234°, or 83 per cent. greater loss under the latter conditions."

On page 228, Mr. Box makes this startling statement—"Table 106 shows that with a radiant body or a clear red heat of 1,860° the loss is about 300 times greater, and at a bright white heat of 2,580° it rises to 4,604 times that amount! He admits the probability of error in applying the rule in extreme temperatures. In any case, allowing for considerable inaccuracy in the figures mentioned, there appears to be very little doubt that the value of the B.T.U. at these high temperatures is at present a doubtful quantity, and that calculations based on the assumption that its value may be taken as a constant at all temperatures will be very misleading.

Mr. A. E. A. Edwards: My experience has been mostly confined to small gas-producer plants. The producers I have had control of have been for such purposes as heating enamelled work, brass melting, and similar materials. There are one or two matters mentioned by Mr. Wall I should like further information on. On page 44 he remarks that—"When gas producers are installed for boiler firing it may nearly always be taken as axiomatic that preliminary heating of the air bears the same ratio to economy that compression does to the efficiency of gas engines." I should be glad to know how Mr. Wall would heat his air—*i.e.*, to any high temperature? His answer upon this point would be interesting, I think. Mr. Wall has exhibited to-night a nozzle used with a producer gas plant. Now it seems to me that that nozzle, instead of being a good one and simple, as Mr. Wall urges, is really more complicated than is necessary for the purpose intended. I take it as an accepted condition that the gas from any producer is more or less a constant quantity. This being so, if the air you supply is at a constant pressure also, any regulation required should be so easy an affair that I think the regulation could be carried out just as readily and, I am sure, with far less risk of complications arising, by the using of an ordinary tap instead of a nozzle. My experience leads me to the conclusion that very likely if an ordinary labourer had the adjustment of a nozzle to attend to like the nozzle exhibited by Mr. Wall, he would lock it so fast that he could get no heat through it at all. I am telling you what my experience has been. For myself, I have had to get the men to severely leave the nozzle alone and to work only by the cocks. I have recently seen at work in North Staffordshire a very interesting example of applying gas producer plant to the heating of kilns for the potting trades. It was the application of a Dowson gas producer plant. The top of this particular furnace or kiln is U shaped, the bottom being square. The bottom of the U is the only leg that is heated. The potteryware when ready for baking is pushed in at one end and carried along methodically, gradually getting heated as it approaches the hot zone. Then the ware is passed along the bottom of the U and passed through the hot zone. The pottery remains in the hot zone, or the hottest part of the kiln, somewhere about half an hour. Then the pottery is passed along the other leg of the kiln or furnace, and is gradually cooled off. The result is that in this particular kiln the pottery is baked in about two to three hours. By the ordinary method of firing a pottery kiln without the employment of gas producer plant, it takes twenty-four hours to get the ware in and out again. The main reason for so long a process is that time has to be allowed for the ware to get reasonably cool after the kiln has been opened before it can be handled. And the same applies to heating the ware. It will be seen by the comparison I have made how great a saving of time is effected at the pottery works in question by the use of the gas producer process. Necessarily a much greater amount of work can be got through, and the economy effected in the output charges is very considerable indeed, The plant I saw has, I was informed, been working for two or three years, and has given every satisfaction. Going back to my own experience with producer plant for brass melting, I may mention that we have obtained some very good results, even when we have employed the exact regulating nozzle which Mr. Wall has exhibited to-night, and which I have been criticising. We used anthracite coal. For large work this would be a very expensive fuel. For the small quantities of work, however, that we required to melt—only about 6 cwt. or 7 cwt. of brass per day—we found it a very economical material. The cost, as far as I remember, was small—certainly less than the coal consumption in a brass melting coal-fired furnace of the ordinary pattern even when well fired. We have now adopted a twin furnace. In this plant the economy is still greater, The heat from the one crucible furnace, after doing its work, passes out through the top and round another similar furnace filled with metal, and so heats that. Really, you will observe, the second furnace is heated up with the waste gases from the first. And, I may assure you, that the work on the second furnace is done effectively. By the employment of twin furnaces, we have been able to reduce the anthracite coal consumption almost one-half—40 per cent. to be exact—of what the outlay was when we worked with single furnaces. If, instead of employing anthracite fuel, we worked with ordinary South Staffordshire, *i.e.*, Black Country firing slack, we could have divided that cost by, at the least, two or three, and this simply because we could have used the gas straight from the producer and not been troubled about cooling it, as we have, of course, to do now. In such an event, the economy of working would, I believe, have been greater than had ever previously been obtained in brass melting—that being the particular work upon which we were engaged.

Mr. Frank Somers: I wish rather to emphasise what Mr. Wall has put before us in his paper than to criticise it. There are one or two points, however, I should like to touch on. On page 39 and again on page 44 he refers to the value of producer gas for boiler firing and remarks "In the case of steam boilers the practice of using producer gas has been too hastily formed on that of using the waste gas from blast furnaces in ironworks, where economy of such fuel has not been necessary or aimed at." I can fully endorse these remarks. And there is another point here I should like to make. In some large ironworks where the waste heat from the blast furnaces is used for boiler firing, cold air is still used to support combustion. This does not entirely prevent good results being obtained. Still, and this is what I want to emphasise, I think much better results would be secured if hot air were used. A small heating furnace might be laid down and attached to the other plant for this purpose. I quite agree with Mr. Wall that the temperature of combustion in boiler furnaces ought to be high. As to the amount of economy to be expected from the employment of producer gas in boiler firing, it may be stated at once that it would not pay to put down a producer plant for a single boiler, but where there is a battery of say twelve or more boilers, there is great economy to be obtained. The difficulty of heating the air preparatory to charging it into the furnaces in the case of a battery is not, however, easily solved. I should like to add a word about the employment of electricity as a power producer in works. Electricity bears somewhat the same relation to power as gas does to heat. There is a slight first loss in producing it, but in its application there is a great gain.

Mr. Ernest A. Dowson: Although not a member of the Institute, I may perhaps be permitted to say a word or two. It is encouraging to find that Mr. Wall is repeating the really strong arguments in favour of gas firing, more especially as the locale of his remarks is within that Black Country which so greatly needs to lay the lesson to heart. Having myself read papers on this subject in various places, I will not now speak as to detailed applications. But I cannot avoid embracing this further opportunity for emphasising the general principle of gaseous fuel as essentially a sound one. There is just one point, also, which I might touch upon in connection with the heating of furnaces by gas. It is that, if any considerable temperature is required, it is essential that some form of heat "regenerator" or arrestor is applied to the products of combustion. Misconceptions on the point prevail in various quarters. But, clearly, apart from irregularity of temperature, or other drawbacks, it is the chimney losses which are so serious in the case of coal-fired furnaces. Here gas comes to the rescue in a thoroughly scientific way. Would-be users of gas sometimes hesitate to incur the expense of building regenerators; but if they would more closely figure out the whole balance in favour of gas furnaces, it will usually be found that the extra first cost is speedily recouped. There are, of course, many processes working at more moderate temperatures. In these cases, however, the products carry away relatively but little heat, so that a simple chimney is all that is needed. Whatever the applications may be, it is of extreme importance that furnaces or other apparatus should be specially and properly designed and adjusted for the individual work in view, and the particular kind of gas to be employed. Turning to a matter which is of special local interest, members are doubtless aware that producer gas is now available in bulk from the mains of the South Staffordshire Mond Gas Company. Assuming that any given works are within reasonable distance of that company's network of mains, it might at least be worth while to consider the use of gas, such as this is, laid on "ready made" at manufacturers' doors. In other cases, where distance is prohibitive, there is *no better method than* to instal gas making plant where required. For the benefit of those who, recognising that gas is regularly employed for open-hearth steel melting, yet doubt the sufficiency of temperature in a narrow-throated gas-fired furnace for wrought-iron tube welding, and some other similar work, the following may be useful: The highest temperature observed in some late experiments in the bed of a coal-fired welding furnace of this type was 1420°C, whereas in a gas-fired furnace of the same size the temperature was 1530°C., and could be maintained steadily at this heat. The question of power production having been touched upon to-night, I do not think it would be amiss to ask works proprietors to give closer consideration to the claims of gas driving. There are now some fairly large gas engines in the district working successfully either on blast furnace or producer gas, and there is room for a great extension in the number of such plants.

Mr. C. E. **Stanier**: Mr. Walter Jones raised the question to-night of the reliability of the British thermal unit as a heat measurement. He has made a set attack upon it. And as one who believes in the accepted theory regarding that unit, I should like to say something in its defence. I understood until to-night that the British thermal unit was an absolutely fixed quantity. How then it can vary, as Mr. Walter Jones has sought to establish, I don't quite see. The ex-president stated, I think—if I rightly caught his remarks—that he had been experimenting on the amount of heat used up in generating steam under varying conditions, and he said that his ascertained results were, I think, that there was a much greater efficiency at the lower range of temperature than at the higher range. Mr Jones seemed surprised at this. But, it occurs to me, that just such a result was surely only to be expected. I I know that the properties of heat at a high temperature are very complicated—and in this matter I go a long way with Mr. Jones, but upon the points I have raised I am at variance with him. Mention has been made this evening of the Allday gas furnace and of the economy which it produces, and an Allday nozzle is on the table. At the works where I am associated, we have had some experience with the Allday furnace in rivet heating. We put down a gas engine to drive an air compressor. As we had the gas in the works already, we thought we would try the Allday furnace, and we had four on approval to try their economy. Well, we put them in, but they were useless for our purposes, and after six weeks we discarded them, and the patentees acknowledged that so far as we were concerned they were a failure. I mean that they effected little or no economy over our ordinary coal-fire heated furnaces for rivet heating. In the Allday furnace there is a small grate at the bottom, and the heat goes up four tiers and then up the stack. Our experience with the Allday furnace was not singular. I say this in palliation of its performance with us. I have seen several rivet furnaces at various times, but I have certainly not yet found a gas furnace for our work which *was a success.* Upon the whole I have found nothing so simple and so good as the coal-fired furnace we now employ. At our works also we have a lot to do in brass melting. We were recently putting down a large new furnace for this purpose. We considered whether we would put in a gas-fired or a coal-fired plant, and after careful thought the coal-fired furnace had it. As I said, it is a big furnace, about 25ft. x 6ft., and the intention was to heat two charges at one operation. The furnace is oblong, about 19in. to the crown of the arch. But, to our disappointment, when we got it up and got it to work, we found that we could not compass what we had desired. We could not heat two charges simultaneously. The width was ample, but other difficulties presented themselves. One of the main troubles was that we could not get the heat uniform all over the furnace. We found we could only satisfactorily heat one charge at a time and this is now placed in the middle of the furnace. Of course, we now have a furnace twice as large as it need be, so we have had to pay for our experience. Still, even making allowance for this, the cost is nothing like what it would have been had we put in a gas-producer heating furnace. One of the objections I have to producer furnaces is that I am satisfied from my experience that the oxidation and scaling is a great deal larger with them than with the coal-fired plant.

Mr. W. G. Birkinshaw: From a considerable experience, I am quite convinced of the utility and economy of gas-fired furnaces for practically nearly all descriptions of metal working. But I agree with the author that the system to answer expectations must be regenerative. There will be very few, I think, who will dispute that this system has undoubtedly been the means of the whole success of the open-hearth system of steel making, and that is sufficient testimony of what it can effect. It seems curious, to say the least, that passing heat through a furnace and then repassing that same heat back again, makes all the difference to the ultimate efficiency of the fuel. But, curious or simple, the fact remains, and it is for us as works and furnace managers to recognise the fact, and to seek to profit by it. Economy was never more to be aimed at in successful works management than it is to-day. Economy of output means lessened dead charges, and lessened dead charges mean increased profits. But economy is not the only benefit that gas-fired furnaces give. They give greater cleanliness, and this quality in its turn brings lessened labour and added efficiency.

Mr. F. W. Page: I have listened to Mr. Wall's contribution with both pleasure and profit, and very much of what he says I can heartily endorse. I have had some experience of the Siemens furnace in treating large work, and my experience is that there is a saving per ton of iron melted of from 10cwt. to 12cwt. of fuel in favour of the gas furnace over the ordinary coal-fired furnace. The author, therefore, is quite right in laying much stress upon this feature of gas-producer plants. But while many ironworks managers would perhaps be quite willing, and anxious indeed, to convert their furnaces from coal-fired to gas-fired plants when considered from the standpoint of economy only, there is another way in which the matter has to be looked at. I refer to the very practical matter of cost, or outlay on conversion. It occurs to me that very probably in an old ironmaking district like Staffordshire, this is the standpoint most likely—and very justifiably too—to be taken by the bulk of the iron trade. There is no doubt that in effecting the change from coal furnaces to producer furnaces the forges and the mill furnaces in the Staffordshire district would have to be very largely re-built. To my mind this circumstance has constituted the principal reason why the more general use of producer gas has not made greater progress here. The matter of first outlay in furnace reconstruction to accommodate the necessities of a gas-fired system frightens many people. Any one, however, who has had practical experience of the working of the two systems side by side, where big work, *i.e.*, heavy, has to be treated, are convinced of the great saving to be effected by the newer method. To hesitate too seriously, therefore, regarding first cost is unquestionably unwise. I repeat that we ourselves can effect an economy by employing the Siemens furnace of from 10cwt. to 12cwt. of fuel per ton of iron melted.

The PRESIDENT moved the thanks of the Institute to Mr. Wall.

Mr. W. J. FOSTER: I have been asked to second the vote of thanks. I do so with pleasure, though I rather hesitate to add to the discussion, for one reason, because I have not yet had much to do with gas producer plant, and what I have had to do has, unfortunately for me, given me great trouble. My experience so far is that the blast furnace is without doubt the most economical gas producer in existence, but the very plentitude of the gas manufactured has been to me the chief difficulty I have had to cope with. Blast furnace managers don't want their blast furnaces as gas producers, but their value to them is, of course, their capacity as reducing plant. Some persons seem to imagine that in the blast furnace we have an ideal gas producer. Such people, however, do not speak from actual experience of the plant itself. The everyday handling of a blast furnace plant would teach them very different. What pig works managers want is less gas instead of more. Blast furnace coke, particularly in a time of trade revival like the present, when coke prices are very high, is much too expensive a material to be converted into waste gas if we can by any means obviate it. Neither do we want a rich gas—the poorer our gases the greater the economy. This must be recognised by us all.

The proposition having been carried,

Mr. CHARLES H. WALL: I am much obliged for the vote of thanks. The question of the British thermal unit of heat has been raised this evening by the ex-president. Mr. Jones has gone into the subject with so much minuteness that it would be impossible—even if the time were available—to follow him into all the details in the course of an unstudied *reply*. *But if he* will let me have his arguments in writing, I shall have no objection to answering them by correspondence. I may say at once, however, that I adhere to the observations in my paper. Until some better standard of heat is evolved than the one we at present possess, we shall have to abide by the British thermal unit as to-day generally understood by the authorities. Mr. A. E. Edwards raised the question of boiler firing and emphasised the necessity of regenerative furnaces I had thought I had made it plain in my paper that for gas firing of steam boilers to be economical, regenerative chambers were essential. If, however, I did not, I beg to do so now, most emphatically. You will never get any great economy without them. Of course, some amount of economy can be effected apart from regenerative furnaces, but not to the fullest degree. Where there is a large volume of waste gases given off from blast furnaces, and it is not used at all under the boilers, a certain amount of this waste can be prevented by the employment of producers even if unaccompanied by regenerative plant. This fact should not be overlooked by ironmasters in discussing producer gas matters. Mr. Edwards referred to the Allday gas nozzle and took strong exception to it, particularly with respect to pressure. My argument concerning the Allday nozzle is this. · If you supply a furnace with air under pressure you do not secure the same pressure by using a cock, as preferred by Mr. Edwards, as you do by using a nozzle. That is the advantage claimed for the nozzle on the table, and I believe it is a sound claim. I agree that there is something for what Mr. Edwards said about the necessity of having an expert to handle the pressure nozzle, but then I think I may with all fairness remind Mr. Edwards that labour that is not expert is always unreliable, and sometimes is apt to prove in the end very expensive. I was pleased with Mr. Edwards' remarks about his experience with the twin furnace and its marked economy. Mr. Frank Somers in his remarks also referred to boiler firing, and I find from his observations that he is much of the same way of thinking as I am. At the President's and his brother's works there are two producer furnaces for which I practically made the drawings. The gas goes from these furnaces under the boilers, and one of the principal objects of the firm in working these boilers is for steam production for the running of a power press. Practically the producer furnace at the President's works is a regenerative one, although it is not exclusively such. For the production of high temperatures, it is absolutely necessary to employ regenerative chambers. But in all these matters a great deal depends upon individual conditions and circumstances, and upon the class of work required to be performed. One type of furnace may be the very thing for one class of work or for one set of circumstances, that, given different surroundings or different requirements, might prove quite useless. All this works managers and works owners should carefully remember in fairness to inventors and patentees, no less than with due regard to themselves getting the best results from producer plant. It is quite possible to throw *out a gas furnace*—as mentioned by Mr. Stanier in the course of the discussion—through no fault of the furnace itself, but because the type of furnace erected, or something associated with it, was not suitable for the particular work required to be done. No general rule, much less any hard and fast rule, can be laid down on these points. Every installation wants deciding upon for itself, and expert experience should be consulted. It is common experience that managers will not always place sufficient confidence in the engineers whom they consult, or better results would often be secured—and, shall I say it?—failure often prevented. Mr. Stanier has instanced a rivet furnace which he says was not a success. Well, he can hardly expect me to say much about that, as I have not seen the furnace, and without personal knowledge it would be difficult to locate the fault. Mr. Stanier said he thought that probably oxidation was greater in gas-fired than in coal-fired furnaces. That I absolutely deny; it is impossible that the oxidation should be more. If such an occurrence ever took place it could only be through gross mismanagement. If the air and the gas is not regulated in proper proportions, any disorder might be reported. By accurate regulation of air and gas any sort of flame desired can be got. Mr. Page's remarks were of a particularly practical sort; and I sympathise with them very greatly. He spoke of the cost involved in altering coal-fired furnaces in present established ironworks to gas-fired furnaces, and expressed the opinion that it was the first cost that in many instances prevented the adoption of the gas furnace. I agree with Mr. Page. I am quite content to believe that it is this question of original outlay in carrying out the desired change that accounts for the comparatively slow adoption of the gas furnace which we have up to the present witnessed. The cost of the construction and erection of a producer furnace when first considered appears, I have no doubt, heavy to many. And, there is no disputing that it is heavier than the expenditure necessary for coal-fired plant. But I should like to ask these gentlemen to look a little farther ahead than first cost. Then I think they would not hesitate so much. If the marked economy which the newer process effects is rightly considered, the point of first outlay sinks in importance very materially, and the expenditure on plant appears in a truer light. It is here that the producer furnace scores. The statement may appear surprising, but I have known instances where the cost of a producer furnace could be saved absolutely in twelve months when put in to supersede coal-fired methods. As has been already explained, the economy of a small furnace is not proportionately so great as of a large one. In calculating the probable saving effected by any one furnace over the coal-fired system the particular size of the furnace has to be considered. In producer plant, too, as in very many other descriptions of iron and steel works mechanical equipment, continuous working or operation is one of the secrets of lessening dead charges. Gas-fired furnaces are more economical if they can be run continuously from Monday morning until Saturday night than if the heat is allowed to go down and the temperature has to be restored. This fact, indeed, must be well-nigh self apparent to anyone giving the matter a moment's thought. Before sitting down I should like to express my thanks for the courteous manner in which my paper has been received.

The meeting now terminated.

The Fourth Meeting of the Session was held at The Institute, Dudley, on Saturday, February 16th, 1907.

The PRESIDENT (Mr. WILLIAM SOMERS) presided.

The minutes of the last Meeting were read, approved, and signed.

Mr. Frank Tissington was elected a member of the Institute.

The PRESIDENT announced that he had received an official intimation from the Dudley Chamber of Commerce that as President of that Institute, he had been elected an honorary member of the Chamber. He was sure they were very much obliged to the Dudley Chamber for the intimation, and he would be glad to attend the meetings and take part in any discussion affecting those trades with which the Institute was connected.

PROFESSOR BURSTALL then read the following paper :—

INTERNAL COMBUSTION ENGINES.

By Professor F. W. BURSTALL, M.A., M.I.C.E., M.I.M.E.

Up to about ten years ago gas or oil engines, while in very common use, were almost entirely confined to comparatively small sizes, that is, up to some 50 h.p. The reason for this was the fact that when working on illuminating gas the cost was too high to prevent the large engines from seriously competing with steam. There were several comparatively big plants working on Dowson gas, but no engines were then made of any size larger than some 200 to 250 h.p.

It may be useful to sketch the type of engine which was then used, the form being in the greater number of cases very similar to that which was originated by Messrs. Crossley Bros., in the early Eighties. With the expiration of the Otto patent in 1889, the two-stroke cycle of Clarke, and the six-stroke cycle which had been brought into use in order to prevent infringements of the Otto patents, were almost entirely dropped in favour of the four-stroke cycle. The engines were single cylinder horizontal types, having a bed plate and outer cylinder in one piece, with an inserted liner The engine was governed on the hit and miss principle; that is, when the speed became too high the gas supply was shut off entirely, and one or more explosions missed, according to the load. The ignition was effected by a hot tube, either of some special metal or porcelain, heated by a gas flame. Connection between the inside of this tube and the cylinder was effected by the opening of a timing valve which allowed a portion of the charge in the cylinder to enter the hot tube and become ignited. The flame then came back into the cylinder and ignited the whole charge. The valves being comparatively small required no special cooling device, so that even in these small engines there was a great deal of heat in the caps which covered up the exhaust valve. Engines of this form were generally worked at a compression of 55lbs. per square inch. The mechanical efficiency was certainly high, some 85 per cent., and one h.p. hour could be obtained on an expenditure of about 24 cubic feet of town gas, having a calorific value of some 550 thermal units per cubic foot.

With all the advantages of economy that the gas engine possessed compared with steam, there arose a considerable demand for an engine of a larger size, that is, powers of 100 h.p upwards, and to be worked with some of the cheap gases of the lower calorific value, made either from anthracite or bituminous coal. When the diameter of the piston was increased to some 19 inches, and all the valves increased in proportion, difficulties came into existence, which were not serious in smaller engines. It was found that the large pistons became very hot when continually working at about the full load, leading in many cases to pre-ignitions—that is, the charge fired during the compression stroke, which not only seriously reduces the power of the engine, but is also liable to cause very heavy stresses on the engine itself, which often lead to serious breakages. The inlet and exhaust valves also suffer from the same difficulty, and become over-heated, and it was found that the hit and miss principle did not give sufficiently close governing for dynamo driving, for which the greater number of these larger engines were called upon to perform. It was from these troubles that the modern large internal combustion engine has been developed.

Some five or six years ago the manufacture of large gas engines was seriously taken up on the Continent by quite a number of firms. To mention only a few of the best known names, there would be the Cockerill engine as developed by the famous ironworks at Seraing, and the Nürnburg engine. Economical conditions on the Continent led to a very considerable demand for engines using the waste gases from blast furnaces, and supplying either air for blowing or electricity. The large number of furnaces put down in Germany gave the engine makers of that country their chance of developing a large engine, and to this fact may be attributed the much larger developments of large combustion engines on the Continent than in this country, where the great majority of blast furnaces installed had their steam blowing plant.

It must also be noticed that on the Continent the manufacture of large gas engines has often been undertaken by those who had had wide experience in steam engine building, and who therefore attacked the problem on the lines which seemed most familiar to them. In this country, however, few of the leading steam engine makers have seriously tackled the manufacture of large gas engines, and the few who have attempted it have speedily dropped the manufacture, as they were unable to produce satisfactory engines. Putting on one side the small engine up to some 50 h.p. working on suction gas, the demand in this country is mainly for engines from 200 to 700 h.p. to work on producer gas. As a rule the governing has to be distinctly good, and the engine is expected to make long non-stop runs, and to give comparatively little trouble in the way of renewals and repairs. Engines larger than this are generally installed to work on blast furnace gas, in which the problem is very much easier than producer gas, owing to the fact that blast furnace gas is mainly carbon mon-oxide, which is not nearly so liable to pre-ignitions as the hydrogen and the hydro-carbons found in producer gas.

The most important large engines of purely British origin are those developed by the Premier Gas Engine Co., of Nottingham, and Messrs. Crossley Bros., of Manchester. The Premier engine makes a special feature of the use of a piston scavenger charge, that is, a current of cold air is passed through the motor cylinder during exhaust, performing the double action of cooling the cylinder and burning all the products. There is no doubt whatever that this is a step in the right direction, as regards both economy in fuel, and also in helping the engine to run continuously at full power, but it has, however, to some extent, complicated the engine and increases the first cost. Up to some 250 h.p. the Premier engine has single cylinders with the inlet valve at the top and the exhaust valve on the bottom of the breech end; the speed regulation being by means of governing the gas from full load to half load, and below that by cutting out the charges altogether. The scavenger air is furnished by means of a differential piston, that is, the motor piston is connected with a larger piston to which is attached the bearings for carrying the gudgeon pin and connecting rod. The air passes through a trunk to an inlet valve, and thence straight across to the exhaust. A very large number of these engines are at work and giving very satisfactory results. Such troubles as were met with owing to heating have now been overcome by the introduction of water-cooled pistons and water-cooled inlet and exhaust valves, which are absolutely necessary when the cylinders are from 24 to 28 inches in diameter. In these engines the piston speed is about 700ft. per minute, and the speed of rotation about 150 ft. per minute. Higher speeds than this are not desirable, owing very largely to the inertia effect, which, with these heavy engines, will frequently amount to as much as 60 to 70 lbs. per square inch of piston area. Indeed, I am of the opinion that speaking generally the speed of rotation of motion in large engines is, if anything, too high, and that they would work much better and smoother were the speed reduced by 10 per cent.

In the larger Premier engines the Tandem principle has been adopted. That is, there are two cylinders one behind the other, and connected by a piston rod passing through a special form of metal packing in the breech of the large cylinder. This arrangement causes an explosion every revolution, and does not require heavier crank shafts and connecting rods, than a single cylinder engine of half the power. In the early days of these engines great difficulties were experienced in finding a packing which would stand the high temperature without excessive wear, but by the introduction of cast-iron spring rings this trouble has been very largely overcome. The valve motion in the 500 h.p. and larger sizes is quite a departure from current English practice. The valves in place of being vertical are horizontal, the inlet valve being above the piston rod, and the exhaust valve below, so that the breech end of the cylinder is exactly the same form as a steam engine, and the clearance surfaces have the least possible area. The valves are both opened and closed by cams in place of being closed by springs alone. My own personal experience of these engines is highly favourable to this type of valve, more particularly in the compression, by raising it above the customary 120 lbs per square inch, in order to obtain additional economy.

In all large engines the hot tube ignition has been altogether abandoned in favour of the low tension magneto. The simplest form of this is an armature which makes a turn by rotation between the poles of a permanent magnet. At the same time the moving points inside the cylinder are pulled apart, the whole motion being actuated by a spring and trip gear, so that the break is very sudden, and produces a spark at the moving points. In general, each cylinder has two plugs, so that if the spark fails in one, it will pass at the other, and so ignite the gas. Extending as is the use of the magneto, both in this country and on the Continent, it has some very serious drawbacks; the principal one being the difficulty of obtaining a spark should the points either become dirty or coated with water. The spark being extremely hot, and the points being somewhat small, in time the metal wears away, and thus gives difficulty. Plantinum, nickel, and iron are all used for sparking points. The first is very costly, but lasts longer than either nickel or iron, but my own experience goes to show that iron points are as good as any.

Many forms of high tension ignition have been employed. That is, where the sparking distance in the cylinder is kept constant, and a current having a very high voltage generated in an induction coil is made to jump the gap at the correct time. I made numerous experiments with this form of ignition as far back as 1895, but was forced to abandon it owing to the difficulty of keeping up the insulation cf the plug, as in those days the extensive use of mica was not contemplated. This form is very widely used on petrol engines for motor work, and is very satisfactory, but it must be borne in mind that the conditions of say a four-cylinder petrol engine, running at 1,500 revolutions per minute, and supplied with such a very inflammable material as air, saturated with petrol vapour, is a much simpler problem as regards ignition than a large slow-speed engine, in which a missed ignition is a serious matter, whereas, with a quicker running motor, it is a matter of very small importance.

The insulation difficulty, and the question of dirt has been practically solved by the Lodge ignition, being the application of a discovery made by Sir Oliver Lodge as to the properties of what he called the "B" spark. In this form, secondary winding of the induction coil is not carried to the sparking plug, but is connected to the outer covering of a Leyden jar, the inner covering being connected to the sparking plug. The primary current from a set of accumulators is arranged to pass at the correct time by means of a commutator on the lay shaft of the engine. This causes a high tension current in the secondary winding, which charges up the coating of the Leyden jar. When the primary current ceases to pass, owing to the rotation of the shaft, the secondary also dies away, and in cutting off the Leyden jar makes a disruptive discharge across the sparking point. The curious property of this spark is its indifference to water, dirt, etc. of any kind, so that it becomes a matter of no importance as to the condition of the plug in sparking. After a long experience of this type of ignition, I am of opinion that it has many advantages over the low tension magneto, as regards the possibilities of adjustment, certainty of ignition, and lack of trouble owing to the dirty or bad insulation.

Messrs. Crossley Bros. have until quite recently built all their very large engines on the vis-a-vis principle. That is, the cylinders facing each other, and two connecting rods driven on to a common crank pin. This arrangement, which originated with the Deutz firm, has a good many drawbacks when applied to sizes larger than from 200 to 300 h.p., the pressure in the cylinder which runs under being in the wrong direction, and some trouble results with regard to inertia difficulties. Quite a number of these engines are at work and doing satisfactorily. The special feature of the Crossley engine beyond those common to all large engines is the use of a balanced exhaust valve, so that the work required to open this valve is reduced, an important consideration when it is borne in mind that these large valves may have to open against a pressure of some 40 to 50 lbs. per square inch. The governing is by throttling the gas, and cutting out below half load. Messrs. Crossley have recently turned their attention to the construction of the tandem type, but until recently have not been able to say much about this type of engine.

Among other large British engines the most common is the three or four cylinder, quick revolution engine, specially adapted for dynamo driving. This engine originated with the Westinghouse Co., but has since been developed to a considerable extent in this country. The speed is from 200 to 300 revolutions per minute. The lubrication is splash, there being an enclosed crank chamber. The governing is by means of a throttle valve reducing both air and gas at the same time, an arrangement which is particularly suitable for electrical work. For some reason this type of engine is not very satisfactory in large sizes, indeed the vertical engine has not been a success with gas. The principal cause for this lack of good working is, in my opinion, due to the fact that the engine has not been made sufficiently stiff. Designers have been content to follow to some extent the general lines of the quick revolution engine as developed by Messrs. Belliss and Morcom. That is, putting the cylinders directly on the top of the casing. Suitable as this arrangement is for steam it lacks the strength which is necessary to resist the action of the gaseous explosion.

To be successful with the vertical gas engine, it will be necessary, to some extent, to return to the steam hammer type of guide, where actions similar to the gas engine are brought into play. The vertical engine has many advantages, and it no doubt will be developed as the need arises. The continental engines are very much more numerous than our own, as regards number of different makers, but they have a very strong likeness to one another, due, I imagine, to the fact that most of them have originated with some one or two well-known men who have been concerned in the development of the large engine from the commencement.

To mention only only a few of the names, we may take the Nürnberg engine, the Cockerill engine, the Erhart, and others. In almost every case these engines are double-acting, with two cylinders driving on to one crank. Very great care is taken to support all the moving parts by means of cross-heads and bearings, so as to relieve the cylinders from the weight of the very heavy pistons. The valve motion is by means of the inlet valve at the top, and the exhaust valves at the bottom; the opening being either by means of eccentrics, or by curved roller paths in which the leverage is variable. Double-acting engines in this country have not found hitherto great favour. Probably the reason for their success in Germany is due to the fact that the blast furnace gas is very largely used, and next that the engines are so designed as to operate with a fairly low mean pressure, some 60 to 85 lbs. per square inch as against the English practice of some 80 to 110 lbs. per square inch Thus the charges are much weaker, and necessarily the heat developed in the cylinder is lower, so that the difficulties due to expansion are not so serious.

In a single-acting engine it is always possible to anchor one end of the liner, and allow the other end to move, whereas with a double action, there being valves at each end, the amount of motion allowed cannot be very great. Therefore expansion sets up considerable stresses in the liners and outer frame. To avoid this difficulty the German engines are cast in one piece, the cylinder, the outside of the motor jacket, and the valve chambers, so as to distribute as much as possible the stresses due to expansion. These double-acting engines have been made up to as large as 2,000 h.p., and there are probably working to-day some 30,000 h.p. of these engines. This is, itself, sufficient proof that the large gas engine has become a commercial success on the Continent, and that it will be so in this country I have no doubt, but I am by no means certain that it will be of the same form as the continental makers. To begin with these large double-acting engines are certainly expensive in proportion to their power. The cost is some £5 per h.p. at the works, whereas those who wish to buy gas engines in this country would probably wish to pay not more than this price for the engine delivered and fixed.

There is also a certain amount of doubt as to how far these large double-acting engines will run when developing their power continuously; that is to say, night and day running without any stops. I rather incline to the opinion that British engineers will prefer to have the multi-cylinder engine—two, four, or six cylinders, either working on to separate cranks, or arranged tandem-wise, and they will prefer cylinders of moderate dimensions, that is, up to 32in. in diameter. Such engines as these we know can be run for very long periods, developing their full power, and I certainly consider that they will not be more expensive than an engine of the same power and double-acting. As to the cost of operating it may be taken that the labour costs are about the same for gas as for steam. The oil can be brought down to the same amount, although in general a great deal more oil is used than is either necessary or advisable.

The entire saving is therefore over the fuel, and ruling out for the moment blast furnace gas, as this in general is a by-product, we shall find that a first-class gas engine will take about 60 feet of producer gas per b.h.p. per hour. In my own tests I have produced this quantity of gas from 1lb. of common slack costing, delivered, some 8s. per ton. That is, the fuel cost per h.p. per hour is ·04d. At the same station a very fine triple expansion steam engine, working with 200lbs. initial pressure and condensing, uses 15lbs. of steam per b.h.p. Direct comparison cannot be made with the same quality of coal, because common slack is unsuitable for firing in the boilers supplying this steam. Taking coal at 10s. a ton and 2lbs. of coal per b.h.p., we get the cost of the steam at ·107d. This does not take into account any steam pipe losses. Still further I have had an opportunity of comparing the coal costs for two very nearly similar steam and gas plants, each being about 400 h.p and working for the same length of time The result is that the coal used by the gas engine is just about one-third ot that used by the steam plant, and I believe that in all cases this economy can be reached.

I have purposely excluded some of the very high figures on gas engines, which I have myself obtained, and only taken those which can be got in ordinary commercial practice. The question of reliability from breakdown is, I am well aware, often brought against the large gas engine, and I regret to say that too often it is true; but it is only to be expected when one considers the large number of types that have been put into operation, and also the lack of knowledge among drivers and operators connected with large gas engines. Given proper care and attention the large gas engine is very little less reliable than the steam plant, and I feel convinced that before many years we shall find the gas engine replacing steam up to quite large powers.

ADDENDA.

Professor Burstall observed that since writing the paper he had obtained some very interesting details with regard to a German gas engine, which information had not appeared in the technical press. It was the Guldner vertical engine and was developed on the lines mentioned in his paper. In general appearance it looked very much like a cylinder placed between the guides of an ordinary standard steam hammer, the only difference being that the legs of a steam hammer are straighter and that they divert outwards on the bedplate You get a perfectly plain combustion chamber and all the weights rest direct on the crankshaft. The results which have been obtained by reliable authorities in testing indicate that this engine is very considerably ahead, both in mean presure and in economy, of any of the existing types of continental gas engines. It is giving a mean pressure of some 110lbs. per square inch, together with a thermal efficiency of over 40 per cent., which corresponds to a consumption of producer gas of about 37 to 38 cubic feet per B.H.P., the calorific value being some 140 to 150 thermal units per cubic foot.

THE DISCUSSION.

Mr. J. W. **Hall**: We are very pleased we have a gentleman here to-night who has devoted so much time to the study of the gas engine question, and he has certainly given us some very interesting particulars. The possibility of obtaining power from producer gas at a fuel cost per h.p per hour of ·04d. is certainly a surprise to most of us in the room—it is assuredly a surprise to me. Now on the question of design there is a great deal to be said. Most single acting vertical engines fail from a defective supply of oil to the crosshead pin, and charred oil from the cylinder falls into the crank pit. One maker provides a piston rod and stripping box to prevent this. The chief objection to the gas engine, however, as it at present stands, is the totally inadequate strength of the crank shaft. Even if a steam engine is working at 200lbs. at the boiler, the pressure on the piston rarely exceeds 150lbs. If we compare this with the gas engine, we find pressures in gas engines of 250 to 450lbs. on the square inch, yet the average gas engine crankshaft to-day is no larger than a shaft which would be supplied by a steam engine maker for a cylinder of the same size. The reciprocating parts of a steam engine can be cushioned on the return stroke, but not those of a single acting gas engine, the momentum of which is equivalent to 50lbs. per square inch of piston area. As the piston travels forward it twists the crank shaft in one direction, but the crank shaft must drag it back again, which is equivalent to pulling the crankshaft in the opposite direction. This takes no account of the effect of occasional pre-ignitions, and I have found in calculating out the strength of crankshafts in gas engines, that the fibre stresses run up to 10,000lbs., 15,000lbs., and even more per square inch, whereas the ordinary steam engine practice is about 6,000lbs. Those are the most glaring defects in modern gas engines, and it is to these that designers will have to turn their attention. With regard to the gas engine superseding steam, for the smaller sizes this is not a question of the future, it is a question of the past. They are so very much more economical and take up less space. But when we get between 15 and 20 inch cylinders giving 50 to 150 h.p. with a single-acting engine, then the troubles begin. We find the amount of attention and repairs required for larger engines are enormous compared with the steam engine, and there are many cases where they cannot be used, where steady driving or reversing is required. The question arises, granting a saving of fuel, how far it is worth while to take advantage of it as a commercial fact. Take the case of a 1,000 h.p. engine. We will suppose that a gas engine consumes 1·8lbs of fuel per b.h.p. per hour. Take the case of steam. We can do the same work with 1¼lbs. under the very best conditions, but take 2lbs. as a fair average Suppose the engine runs for 3,000 hours per year, the difference in the cost of the fuel will be about £100 in favour of gas a year. Now what have you to set against that? Well, the first cost of the gas engine and the steam engine is much the same. But the wear and tear is greater in the case of the gas engine and the quantity of oil that has to be used will undoubtedly be greater. The water required is pretty much the same, but the risk of a stoppage is very much greater with gas than with steam. If you run your gas engine for 24 hours without a stop year in and year out you get a greater saving of fuel but you have this risk of stoppages, for large gas engines cannot run many months without stoppages for cleaning. Some time ago we had a discussion in this room upon blast furnace gas, and I see present this evening the gentleman who said that the economy in using blast furnace gas in gas engines compared to raising steam with it, was something like 6 to 1. I said at that time that 3 or 4 to 1 would be nearer the point. We then had but little knowledge of the efficiency of engines driven by blast furnace gas, or at any rate I had not. Now I find that from 80 to 100 cubic feet of gas is a reasonable amount to be taken by a gas-blowing engine. From experiments made in the North of England it appears that it takes rather more than 16 cubic feet of gas to evaporate 1 foot of water, and a large steam engine can be made to run with about 12lbs. of feed. Other figures show that the fuel consumption when raising steam in the ordinary way is from twice to 2½ times as much as when using blast furnace gas. True you have a reduction in the accessory plant—the small engines, tanks, pumps, &c., which are required with a large steam driven blowing engine, but these will be pretty well met on the other side of the account, by the cost of the gas-washing plant. The cost of the engines themselves will be about the same. What I think is likely to come forward very largely in the future is the steam blowing-turbine. There are only three bearings in the whole machine, there are no reciprocating parts, and I think in most cases where there is no other use for the blast furnace gas, that we shall see a large development in steam turbines for blast furnace blowing. I believe two or three are going to be put down in this neighbourhood. If you have some special additional outlet for your superfluous gas then you may find it worth your while to prepare it and to use part of it in your blowing engines, but otherwise it becomes a question between the gas engine and the steam engine, and then you have to consider whether the economy of a gas engine is sufficient to counterbalance the extra safety and reliability of steam. Steam turbines, as now made, can, by means of a by-pass valve, stand a 50 per cent. extra load, and extra speed can be obtained by extra firing. But in the case of a gas engine it often happens that just when extra power is required, the gas falls off. I think, therefore, we shall see further developments in steam turbine blowing unless there are certain exceptional circumstances in which any superfluous gas which may be made can be properly utilised outside the engine itself.

The President: We were pleased to hear Mr. Hall make a reference to the paper of Mr. Allen, and we should be glad to hear what Mr. Allen has to say on this important subject.

Mr. Horace Allen: I have listened with very great pleasure to all Professor Burstall has told us. I think he has described actual facts and not discussed the matter theoretically, but while I have Mr. Hall's remarks in my mind I should like to say a few words with regard to those, and with respect more particularly to his allusion to my former paper. Mr. Hall dwelt on the alleged economy of blast furnace gas being burned under boilers. I have seen the time when blast furnace gas did not seem to answer. It went outside the boiler as much as underneath it, because of the draught. Since then, however, attempts have been made to introduce a higher class of boilers suitable for burning gas better. That is as it should be, and the tests to which Mr. Hall refers relate to a higher class of boiler. But sometimes the gas is bad and won't raise steam anyhow. That is due largely to changes in draught. It is very difficult to get a satisfactory draught, and the varying atmospheric conditions, and cross winds, etc., reduce the draught very often by 50 per cent. Just another instance in regard to the alleged failure of gas engines, and where steam engines would come in. I have in my mind some furnaces which had to stand for a certain purpose. There was a steam plant which had been recently improved by adding combination chambers to the boilers to get a better draught, and after this stand they could not be started again. The people could not raise sufficient steam even to run the skip to the top of the furnace, and they had to start a gas engine in order to get the furnace plant to work. That is an instance which speaks well for the gas engine under certain circumstances. I thought recently I would look over a number of specifications to see what direction invention was taking with regard to internal combustion engines, and I found that out of 38 gas engine inventions which I examined, the largest numbers referred to ignition. Nearly all referred to electric ignition, and there is no doubt that ignition has been the trouble more or less throughout. Carburettors followed next, preparing the charge was the subject of 7 inventions, valve gear 5, and silencing 2. The peculiarity of electric ignition, either by the high tension or low tension method is that the electric discharge causes particles of dust to fly to the point, and that soon becomes clogged up, and then the arc refuses to ignite the gas. Sir Oliver Lodge's new method will, no doubt, overcome that difficulty. The great thing is to try to get the points further apart, but this necessitates a higher tension to bridge the interval, and that higher tension is followed by difficulties. I was interested in Professor Burstall's description of the Premier engine, but was rather disappointed in one way, about the inconstancy of the design of the engine. About two years ago a gentleman called upon me and said, "What do you think of the Premier engine?" I did not quite know his object, which happened to be a commercial one. I said, "What do you call the Premier engine? I have looked at various designs all purporting to be Premiers. I don't know whether the Premier Company have since reached any sort of finality, but I believe the latest Premier is a scavenging engine, and so although the scavenging engine gives very good results, and the tests are excellent, yet, as I say, it has been rather uncertain as to which you could call a Premier engine.

Mr. WALTER JONES: I was very much struck with the remarks about the Guldner gas engine, because if the results attributed to it are correct it would apparently cost in working only about one-fourth of the best triple expansion steam engine, and I can quite understand that if we can get down the cost of gas to one-fourth the cost of steam it will not be long before we shall find gas engines replacing steam engines for large powers as well as small. I am not interested in gas engines, but it strikes me a good way would be to standardize a certain sized unit, say 250 brake horse power, and if you wanted anything beyond that you could put down another, or a third, or even a fourth, to make up the power required, something like a train of rolls in an ironworks. I think in that way the cost would be got down very materially. No doubt the cost appears high to gas engine users at presents but you can quite understand that engine builders do not get orders for very large engines every day, and the expenses in designs and pattern, and so forth is very heavy, and if they were to be standardized the same as steam engines, the cost would be reduced. I feel that we are very much indebted to Professor Burstall, and I propose that the very hearty thanks of the meeting be given to him for the excellent paper he has put before us.

Mr. R. G. **Mercer**: I would have liked Professor Burstall to have given us more particulars about the new German engine. I don't see why the paper should have been entitled "Internal Combustion Engines." He has devoted so much attention to gas engines and is so much enamoured of them that I really think a very good title for the paper would have been "The Professor's Love Story!" He has dealt with some types of gas engines very exhaustively, and has mentioned that there are some other engines in the world. He gave some criticism of the Westinghouse type of engine. The fact is, with regard to lubrication, the maker cannot control the use of oil in an engine. The user can employ as much oil as he likes, or as little as he likes. The Westinghouse Company have brought out a vertical tandem type of engine which has been on the market since August, and have over 9,000 horse power at work. It is an 8-cylinder gas engine with 2 or 4 or 6 cranks, and the oil consumption is extremely low. There is one at work in the North of England of 250 horse power which only takes 2 gallons of oil per week. The lubrication is no longer splash, but forced, and this, I believe, is the rule with good engines now. We are not going to make any more single-acting engines. The ignition, I think, you are all very well aware of. We think we have as good a system of ignition as any engine on the market, if not better. To my mind there is no doubt that accessibility is a very important point in any engine. One speaker said he thought all gas engines were more or less unreliable. I can hardly agree with so sweeping an assertion as that. We say that in our latest engine we have great accessibility. The crankshaft of our previous pattern of engine was perhaps not very accessible, but we don't worry about that. The pistons in our new engine can be taken out and put on the floor inside of 35 minutes. That would be impossible in some other designs. We put down a 1,500 h.p. engine the other day and there was no vibration even when it was running 40 per cent. overload. I think it is sufficient to demonstrate the soundness of this design of engine when great firms, after seeing only one, can place an order for four of 750 h.p. each straight away.

Mr. **Gibbs**: The gas engine may be said at present to be comparatively new, whereas the steam engine has been on the market now for a number of years, and many economies have gradually been effected in its workings. I believe there is from 70 to 75 per cent. of heat lost in some steam engines by water jacketting. I should like to know the Professor's opinion on that point. Doubtless further improvements will be introduced in gas engines, and I am certain that they will be used more and more, not only in the iron industry, but in other trades as well.

Mr. W. **Fennell**: I am not a member of the Institute, being only a visitor here, but the subject is an interesting one, and I should like to be allowed a few remarks. I am an electrical engineer, and I am looking for a good gas engine. It has been my unpleasant duty during the last few weeks to interview numerous salesmen in connection with gas engines, and the general effect on me, I am sorry to say, has been rather bad. I have been struck with the fact that in each case there is asserted to be one gas engine which is good, all the rest are all wrong, so that in turn I have been told that each one is bad, and "whichever you put in please don't put in that one." Moreover, I know of at least three electrical stations—Leyton, King's Lynn, and Redditch—where gas engines used to be running but are not running to-day. It seems to me that it will be the increased electrical requirements that will eventually produce a good gas engine. About fifteen years ago electrical engineers began to demand an economical steam engine, and, I suppose, that has had a better effect upon the development and upon the economy of steam plant than any other circumstance. Probably a similar development will take place with respect to gas engines. But still there are difficulties to be met which are rather "facers." We hear a lot about large gas engines one day, and the next we are told that the large gas engine plants of the future will be made by a combination of several small or medium sized ones. That seems to me practically an admission that we cannot make large gas engines. It seems to me that about the only firm in this country who are making large gas engines are Messrs. Mather and Platt, of Manchester, who are making a 1,000 h.p. gas engine with only one cylinder. There are some running at the Shelton Iron and Steel Co.'s works, Stoke-on-Trent. It is not only double acting, but it is a two-cycle engine. You get the same even turning moment as you would if you had several small engines in one line on one shaft. There is another point of great importance in connection with this subject, and that is the real operating cost of plant. As you get out of the train at some of the manufacturing towns you see from the advertisement plates that you can get 20 h.p. for one hour for 1d. with suction gas plant, but I have been working it out and I feel we shall be very lucky if we do it for ·2 of 1d. per h.p. hour. It looks high, but that is what I shall have to suggest to my committee. I have been guaranteed ·8lbs. of coal, but that is on test. Perhaps Professor Burstall can give us some idea about that. What are wanted are some year in and year out figures of the cost of practically running a good sized plant working with producer gas on the very latest lines and giving off about 5,000 to 6,000 h.p. Such figures would be of very great value. I have not seen any such information, and I don't know where to get it. People who have gas plants seem to think that the very best turn they can do the manufacturers is to say nothing about them, and that frightens engineers and makes them hesitate to adopt gas for fear it should not prove reliable, whereas, of course, one knows one can rely upon a steam plant. I have had much pleasure in listening to Professor Burstall, and I feel it has been a very useful paper, Mr. E. A. DOWSON: I have a few notes here and perhaps I may be allowed to allude to them. There is often much vagueness in stating the cost of gas production, the terms used are often obscured, and bearing in mind what has been said about the cost of a horse power this evening—I mean the varying estimates of the several speakers—I should certainly like to encourage any people who may be contemplating the use of gas, to ascertain exactly what items are covered when figures are quoted to them for, let us say, a 30 or 40 h.p. gas engine. My experience with suction gas has been that about ·2 of one penny per b h.p. per hour will cover all the items of expense. But you must remember you must not only include the cost of the fuel, but the water and incidentals, and other sundries. As to ·8 of 1lb. of fuel per h p. per hour, I think it is an impossibility for it to be done, and I am surprised at anyone advancing such a statement. Two years ago in Birmingham, in a paper, I dealt with large gas engines. It is hardly fair to the large gas engine to put it against the steam engine. The large gas engine is only, so to speak, in its youth as yet, and Mr. Fennell is perhaps a little unmerciful in his criticism. We shall no doubt be able to compete with them in time. The original Westinghouse series of gas engines were built in America, and the Yankee engineers skimped the metal. That is at the bottom of a good deal of trouble. With Mr. Hall and others I was intensely interested in hearing about the Güldner engine, and I am certain any further information about it would be exceedingly acceptable. With regard to vertical engines, I am not going to say that a vertical engine is necessarily a failure, indeed, I think I can adduce as an example of decided success a very excellent design of vertical gas engine which has been introduced by the Diesel Oil Engine Company. I very much admire the design of that engine, and if people were to follow out that design we should have very much less trouble than is usually the case. As to lubrication, there is a lot of trouble due to splash lubrication. The conditions in gas and steam practice with regard to lubrication are quite different. The secret of the whole thing lies in forced lubrication, it is forced lubrication which I feel is wanted to supply the oil in small quantities just where required. As to reversing engines, Mr. Hall, in most of his remarks, which were exceedingly interesting, has usefully dealt more especially with rolling mill engines as used by ironmasters. In this week's *Engineer* there is a very interesting account of some new tackle which has been brought out for that very purpose.

Mr. R. BUCHANAN, as Vice-President of the Institute, seconded the resolution. He said: I am sure Professor Burstall has given us not only an excellent paper but an excellent text for discussion. My little experience has been mainly with regard to the speed of engines. I have had to deal with several types of engines whose ailments have been somewhat numerous and I have found that the means of diagnosing what is wrong with them is rather limited, and so seeing that my experience is so little I shall not endeavour to decide the battle which we have had to-night between the various exponents of the different types. It has been a great pleasure to me to have heard such an authority as Professor Burstall is universally admitted to be, giving us his views of the various types, especially of the large powers. One speaker rightly referred to the fact that the gas engine is comparatively new, and I think we are a little apt to be excessively critical to expect that the gas engine will, in a very short time, come to the same level of efficiency which the steam engine took a very long time to attain. I can remember when triple expansion came in, and it was held to be, as it undoubtedly was, a tremendous advance. The people of the United States, and of this country, are not likely to sit down without completely remedying the drawbacks and disappointments which some of the users of high power gas engines are said to have experienced. It is only to be expected that the same progressive spirit and the same knowledge, which has brought the steam engine to its present development, will also bring these high powers in the case of the gas engine to the success which we hope and trust they may soon reach.

The resolution was carried unanimously.

Professor Burstall, replying on the discussion, said: Mr Hall's remarks are interesting. Lubrication need not be a large item. My own engine, the Premier (I call it my own because although the Premier Company built it I designed it myself) has a cylinder diameter of 16 inches, and the crank pin is 10 inches in diameter, and it does some very heavy work successfully. It develops 100 horse power yet it only takes 1¾ pints of oil per day of 10 hours. Now I quite agree that with large engines there is often some trouble, but considering that ten years ago there was not a 100 h.p. gas engine in existence, I think we have developed very quickly, in fact, if anything, almost too quickly, and I think that has been the trouble in some cases. Mr. Allen alludes to the Premier Company frequently changing its designs, and he is right. As to the different sorts of valves, I know them all pretty well and I think they are rather too varied. Mr. Jones suggests the small sizes of gas engines being standardized. That is why I recommend many cylinders. Mr. Fennell says that working several small engines together is an admission that you cannot make large engines, but I don't see that. I think it is because more cylinders mean greater flexibility. Just as you get greater flexibility if you have several small engines in combination, so you get flexibility by having several cylinders in one engine. As to Mr. Mercer, one hardly takes him very seriously. I am aware of the advantages of the vertical engine, but I would point out that Herr Güldner was the chief designer of the Diesel Oil Engine Company. He has made a vertical engine, made it very heavy and altered his arrangement of valves, and has produced an engine which seems to me a tremendous advance. With regard to my own engine I cannot say much now because the results are to be given to another body shortly, but I may say that I have myself produced 1 h.p. with 36 cubic feet of producer gas. That is done by pushing up the compression to an enormous extent, which is how you get the economy. Mr. Gibbs asks what can be done with regard to further improvements. Well, a very interesting paper as to prospects in this direction was read by Mr. Dugald Clark. I have got to 43 per cent. efficiency. Two years ago I thought that 40 was as much as could be got. I hope before I finish with the gas engine, or the gas engine finishes me, to get 50. Mr. Fennell says he is an electrical engineer wanting to put in a gas engine for an electric station, and he wants to know what type to choose. My advice to him is not to put one in at all. Because if you want a central station driven by gas to be accurate and good you must not do as was done by the different towns mentioned. That is to say you must not expect your electrical engineer to be able to choose and control the gas department, What you ought to do is to cut your station into two parts and let your electrical engineer do one part of the work and the gas engineer the other part. Therefore he will be very wise if he says to the committee, "Gentlemen, I don't understand gas, I do steam; let me put in steam." As to operating costs; it will be found that everything depends on the load factor. The outside figure you can do is on a 50 per cent. load factor. In that case the total operating costs, including fuel, oil, petty stores, labour administrative expenses, and materials, run out on 1,000 Kilowatt engines to ·35d. per Kilowatt, that being in South Africa. And there is no sort of doubt that that can be actually done. With reference to the Körting engine, I do not think that is a very economical engine at the present moment. Gentlemen, it is getting rather late, and I will claim your indulgence and terminate this discussion.

The Fifth Meeting of the Session was held on Saturday, March 16th, 1907, at The Institute, Dudley, Mr. William Somers (President) in the chair.

The Minutes of the previous Meeting were read, approved, and signed.

Dr. **FINDLAY** then read the following paper :—

SOME PRINCIPLES OF PHYSICAL CHEMISTRY AND THEIR APPLICATION IN METALLURGY.

BY DR. ALEX. FINDLAY, M.A., University of Birmingham.

It was with a feeling of peculiar pleasure and satisfaction that I accepted the invitation to address you this evening on some of the Applications of Physical Chemistry to Metallurgy, not only because of the honour which such an invitation carried with it, but also because it emphasised the close—indeed, vital—connection which exists between those two sides of scientific investigation which we call pure science and applied science. For too long, unfortunately, investigators in pure science, who carried on their work under the inspiration of the noble belief "That in itself alone shall its reward be, no alien end blending therewith," had suffered from the lack of appreciation and encouragement by those who could see no relationship between the work and discoveries of pure science and the important industrial operations in which they themselves were engaged. Happily, that state of feeling is now passing away, and each year sees the ties between pure and applied science becoming stronger and more intimate, and the reconciliation is fraught with advantage to all. I consider it, therefore, a privilege, which carries with it a responsibility, to be allowed to lay before you some of the principles, more directly bearing on metallurgy, of that recently created branch of science which has exercised during the past ten years, and which will assuredly continue to exercise in the future, an important influence on the progress of investigation, whether in pure science or in the application of science to the various industrial processes.

When we turn, now, to the consideration of metallurgical investigations, we perceive various directions in which inquiry can proceed. Thus, in the case of pure metals, we can investigate the changes, if any, which take place in the properties of the metal through the application of heat followed by slow or sudden cooling; or, in the case of alloys, we may study the variation of the properties, *e.g.*, elasticity, tensile strength, hardness, and others, with change in the composition of the alloy as given by chemical analysis. But even when the chemical composition is the same, the properties may be very different, owing to *difference in* the state of combination of the constituents, or to a difference in the texture of the alloy. We therefore find that the microscopic examination of alloys is of the greatest importance in affording information as to the character of an alloy

There is, however, a rather more general manner in which the behaviour of metals and alloys can be studied. The preceding methods of examination tell us, it is true, the nature and arrangement of the constituents, but they leave us ignorant of the relationships existing between the different structures and of the laws governing their formation or their disappearance. Well, now, it is to the elucidation of these relationships and laws that Physical Chemistry applies itself; and it is to the consideration of the general principles involved in this domain of inquiry that I ask your attention this evening.

Even a cursory examination of the subject will teach that we are dealing with the co-existence of different parts of matter, each of these parts being, however, homogeneous. Thus, on examining microscopically a specimen of an iron-carbon alloy, we may see patches of ferrite co-existing with patches of graphite or of cementite; and although different small specimens of such an alloy would have different compositions, the composition of each of the patches separately would be uniform or homogeneous. Now, each such homogeneous mass of matter which is physically distinct from other masses of matter is called a *phase*; and it is of no consequence whether the phase is a solid, a liquid or a gas, an element, a compound or a solution (*i.e.*, a homogeneous mixture). We see, therefore, that what we have to consider is the conditions for the co-existence of, or equlibrium between, different phases, quite irrespective of the composition of these phases.

Let us take a very simple and familiar example. Suppose we have a quantity of pure water in a closed vessel kept at some constant temperature. Vapour will be given off and will create a certain pressure within the flask. We have now two phases co-existing, viz., liquid and vapour, and the pressure of the vapour which is given off increases as the temperature is raised. At any given constant temperature, however, the vapour pressure is constant. We see from this, then, that liquid water and vapour can be in equilibrium under different conditions of temperature and pressure, but if we fix one of these two factors then the other will assume a definite value. We shall for the present suppose that temperature and pressure are the only two external influences which can alter.

Let us now suppose that the vessel containing the water and vapour is cooled down; then we shall find that at a certain point ice will form, and we shall now have ice, liquid, and vapour co-existing, *i.e.*, three phases of the substance water. This condition of equilibrium, however, can continue only when the temperature and the pressure have certain definite values. If we attempt to alter the temperature by the addition or abstraction of heat, we shall merely cause one of the phases—ice or water—to disappear.

From these examples we see that in the former case we could alter at will one of the variable factors, temperature or pressure, without destroying the co-existence of the two phases water or vapour; but in the latter case we no longer had this freedom. The co-existence of ice, water, and vapour is dependent on a definite temperature and pressure, and if we alter these the co-existence of the three phases becomes impossible. Such a system or collection of phases is said to be *invariant*. We may also say that the variability of such a system is zero, or that it possesses no degrees of freedom. If, however, as in the former case, we can alter one of the factors on which the co-existence of the phases depends, viz., temperature or pressure, the system is said to be *univariant*. That is to say, the variability of the system is one, o it possesses one degree of freedom.

Now, the above examples, as well as all other cases whatsoever, of co-existence of or equilibrium between phases, are in accordance with the general rule or law known as the Phase Rule or Phase Law, one of the most important laws in the whole of Physical Chemistry. With the help of the Phase Rule we are enabled to group together the different cases of equilibria, to gain an insight into the relations which exist between different systems, and to follow the conditions for the formation and permanence of systems. Wide as is its application, however, this rule or law can be summed up in an exceedingly simple formula, viz.:

$$F = C + 2 - P,$$

or, translated into words, the degree of freedom of a system is equal to the number of the components of the system plus two and minus the number of phases present. Thus, when we have the one component water existing in two phases, liquid and vapour, the number of degrees of freedom which it will possess will be $F = 1 + 2 - 2 = 1$. That is, the system is univariant, as previously stated. If there are three phases, ice, water, and vapour, we have $F = 1 + 2 - 3 = 0$. The system has no degrees of freedom, or is invariant.

This, then, is the Phase Rule, and the great law of Physical Chemistry which it will be my endeavour to explain to you this evening. In passing, I may be allowed to say that had it been my intention to plead for a fuller recognition of pure science by those engaged in the industrial applications of science, I could have found no better text for my discourse than that of the history of the Phase Rule. The simple rule stated above was obtained as an abstract mathematical generalisation by one of the greatest American mathematicians and physicists, Professor Willard Gibbs, who died just four years ago; and it is easy to imagine how anyone who dared to suggest the practical utility of that collection of mathematical symbols would have been laughed to scorn. And yet, at the present day, after a period of some thirty years, that abstract generalisation is recognised as the indispensable guide through the mazy tangle of relationships met with in the various alloys of iron and carbon, and of other metals. This recognition we owe in greatest measure to the Dutch Physical Chemist, Bakhuis Roozeboom, whose recent death has robbed Science of one of its most devoted and gifted workers.

We must now go on to the discussion of a number of points in connection with the behaviour of substances and groups of phases, which we shall find to be of great importance in metallurgical investigations. In order to follow better the connection between the different systems as indicated by the Phase Rule, we shall make use of the graphic method of representation. Thus if we measure pressures along a vertical; and temperatures along a horizontal line, we shall get the following diagram representing the various conditions under which the various phases of water (or any other single substance) can exist. (Fig. 1).

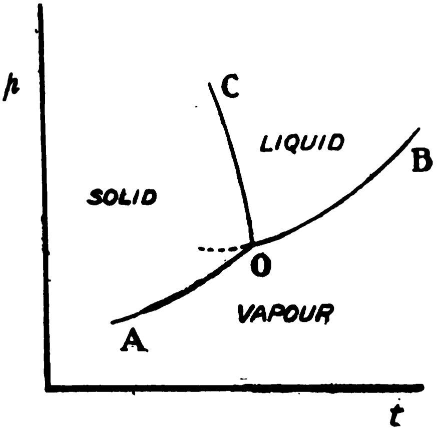

Fig 1.

The curve AO represents the different values of temperature and pressure at which ice can exist in equilibrium with water vapour; OB, the conditions under which liquid water can co-exist with vapour; while OC represents the conditions of temperature and pressure under which ice and water can co-exist. The curve OC, therefore, represents the variation of the melting point of ice with pressure. As you know, the melting point is lowered by pressure, and this is indicated by the inclination of the curve to the left.

This relation of the melting point of ice to pressure may be taken as an illustration of a very important law or theorem, the theorem of Le Chatelier. Whenever a change is accompanied by a diminution of volume, it will be facilitated by an increase of pressure or, if the change is accompanied by an increase in volume it will be facilitated b diminution of pressure. Thus the melting of ice is accompanied b diminution of volume and will therefore be facilitated by an incre of pressure, *i.e.*, the ice will melt at a lower temperature. Furt whenever a change is accompanied by an absorption of heat, it will facilitated by the addition of heat, and when it is accompanied evolution of heat, the change will be facilitated by abstraction of h Thus, the vaporisation of a liquid is accompanied by an absorption heat, and consequently will be facilitated by the addition of heat other words the vapour pressure increases with the temperature.

Each of the above systems of two phases constitutes, as the Pl Rule shows, an univariant system, and we see, therefore, that an variant system is represented in our diagrams by a line. The sys ice, water, vapour, constitutes an invariant system, and the condition its existence is represented by O, the point of intersection of the t curves AO, BO, CO. An invariant system is therefore represented point in our diagram. The different areas in our diagram represent conditions under which one phase can exist. Since one phase can e under different values of the pressure, even when the temperatur constant, the state of the system will be defined only when we have fi *both* temperature and pressure. In accordance with our previous de tion, therefore, a single phase has two degrees of freedom or is *bivaria* and such a system is represented by an *area*.

The different equilibria represented by Fig. 1 are what are ca *stable* equilibria; they are the most stable condition of the substa water under the particular conditions of temperature and pressure. you know that water can be cooled below its ordinary freezing p (0°C), *i.e.*, can be super-cooled without solidification occurring. shall then have water existing in contact with vapour at temperat below that represented by the point O in Fig. 1. This is indicated the dotted continuation of BO. Now, although supercooled water vapour can co-exist apparently for an indefinitely long time, provi the supercooling is not too great, it is not the most stable system at temperature. Such a system is then said to be in *metastable* equilibri We here meet with a phenomenon which is of very frequent, alr universal occurrence, viz., that when we alter the external conditio system does not at once pass into its most stable state of equilibri and in order to ensure the change, it is necessary to add a small quan a "nucleus," of the most stable phase. Thus, on putting a piece o into supercooled water, the whole liquid solidifies. As the degre supercooling is increased, a point is generally reached at which s taneous solidification occurs, owing to the spontaneous formatio "nuclei" of the stable phase within the liquid.

Not only does the extent to which supercooling occurs vary in the of different substances, but the rate at which crystallisation takes p the supercooled liquid also varies. As the degree of supercooling :reases, the velocity of crystallisation also increases, until a certain int is reached at which the velocity is a maximum. On cooling to a nperature below this, however, the velocity rapidly diminishes, and ιy become practically zero. The supercooled liquid may in this way ss into a "glass," which will remain practically permanent even in ntact with crystalline solid.

Now in ordinary glass and in the glassy slags we have familiar amples of liquids supercooled to such a degree that crystallisation curs with practically infinite slowness. If, however, glass is heated, a nperature is reached, much below the melting point of the glass, at iich crystallisation occurs with appreciable velocity. The glass then comes "devitrified."

There is another property of glasses and slags which must be noted. ιey are amorphous, and on being heated will, therefore, pass *gradually* m the solid to the liquid state. They possess, therefore, no true lting point. The melting points of slag sometimes given are not ıe melting points, but merely softening points—points at which the gs reach a certain degree of fluidity. Conversely, when a slag is oled, it may show no definite freezing point or solidification point, ing to the sluggishness with which crystallisation occurs; for it must remembered that we can rightly speak of a freezing point only when re is separation out of crystalline solid. Now, in order to allow of stallisation occurring, we must add, if that is possible, some of the stalline material which would separate out, or we must maintain the percooled liquid at a temperature in the neighbourhood of the freezing int for some time. The cooling must, therefore, take place very wly. How slowly, will depend on the velocity with which the superoled liquid crystallises, and it may therefore not be possible, within asonable limits of time, to secure crystallisation at all.

With regard to the methods of determining the freezing point of a bstance, practically the only method of interest to metallurgists is the termination of the cooling curve—a method, no doubt, familiar to you l. When we examine the cooling curve of a liquid we find that it has form similar to that shown in Fig. 2. As the liquid cools, the fall of

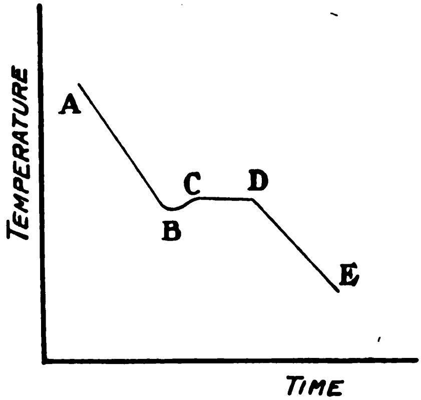

FIG 2.

temperature will be represented by the curve *a b*, and as supercooling generally occurs, the point *b* will be below the true freezing point. When crystallisation commences, the latent heat of fusion is given out and the temperature now rises to *c*, and remains constant (provided the temperature of the cooling bath is not too low) until complete solidification has occurred. After complete solidification has occurred, the fall of temperature again becomes uniform, We see then that the freezing point is indicated by an arrest in the cooling curve; and we must again bear in mind that the definiteness of the arrest will depend on the rate of cooling, on the rate of crystallisation, and on the latent heat of fusion.

So far, we have considered the equilibrium between solid and liquid, but it is not infrequently found that a solid substance can exist in more than one modification. Thus a well-known case is sulphur, which exists in the rhombic and in the monoclinic forms. Of more interest to metallurgists is the case of tin. Tin, in its ordinary form, is a white lustrous metal, but it is also known in the form of a grey crystalline powder. Now, when we enquire into the conditions under which these two forms of tin can co-exist, we turn to the Phase Rule, and find that two phases of one substance constitute a univariant system; that is, under a given pressure, the two phases can co-exist only at one definite temperature ($F = 1 + 2 - 2 = 1$). If now we consider the co-existence under atmospheric pressure, we see that there can be only one temperature at which white tin and grey tin can exist together in stable equilibrium. At any other temperature one of these forms must ultimately change into the other and disappear. In other words, at temperatures below that at which the two forms can co-exist, one of the forms of tin will be unstable (or metastable), while at temperatures above that at which both forms can co-exist, the form which was stable at lower temperatures will now become unstable (or metastable), and that which before was unstable will now become stable. We see therefore that there is a point at which the relative stability of the two forms of tin alters, and this point is therefore called a *transition point.*

In order to determine the transition point, use was made of the fact that the specific volume of white and grey tin is different—the volume of the latter being greater than that of the former. By determining the temperature at which this change of volume occurs, it was found that the transition point is about 20°C or 68°F, and that below this temperature the grey form, above this temperature the white form is stable. We see then that white tin is, under ordinary circumstances, except in the warm Summer weather, less stable than grey tin. It should therefore pass spontaneously into grey tin. But you know very well that white tin remains unchanged for many years, even in the cold of Winter. How is this? Well we have here a phenomenon exactly analogous to a supercooled liquid. The white tin at all temperatures below 20°C is metastable, but the velocity of transformation (corresponding with the velocity of crystallisation) is very slow, and the white tin therefore possesses considerable permanence.

I should like to emphasise this point, because it is repeatedly met with in metallurgy. Because a certain solid substance or certain form of a substance seems to remain unchanged for many years, we must not argue that that substance or form of substance is therefore stable. Let me anticipate a little and refer to the case of an iron-carbon alloy containing say 0·8 per cent. of carbon You know that if this alloy is heated to above 670° and suddenly cooled, you get a homogeneous mass, called martensite, and this may remain unchanged for many years. If, however, you cool the alloy more slowly, you find that below 670° the mass becomes heterogeneous, forming a mixture of ferrite and cementite called pearlite. In the case of martensite at the ordinary temperatures, therefore we are dealing with a metastable system in which the velocity of transformation to the stable form is small.

Now there are various ways in which the transformation of a metastable form can be accelerated. The first method is "innoculation" with the more stable modification. Thus, white tin will undergo transformation to grey tin more rapidly when it is brought into contact with the latter. But even in this case the velocity may be, and is indeed, very small. Another method is by means of solvents. It can be shown that the less stable form is more soluble than the more stable form; consequently if we have the two forms present along with a solvent, the less stable form will dissolve to a greater extent than the more stable. The solution will thereby become supersaturated for the stable form, which will accordingly separate out. In this way the less stable will ultimately pass into the more stable form. Thus it was found that the transformation of white tin into the more stable grey modification, takes place more rapidly in contact with a solution of tin ammonium chloride, so-called pink salt, than in the ordinary dry condition.

A third method by which transformation of the metastable form can be accelerated is by means of catalytic agents. By a catalytic agent we mean a substance which, *apparently*, by its presence alone, accelerates a change which would however take place spontaneously with greater slowness. It, so to speak, lubricates the re-action by diminishing the resistance to change. With regard to the way in which catalytic agents work, much discussion has recently taken place; but without entering into this we can say that relatively very small quantities of the catalytic agent may produce very great alterations in the velocity of change. Thus sodium sulphite in solution is oxidised by the oxygen of the air to sodium sulphate, but the velocity of this process is reduced by the presence of copper in the solution; and so marked is this effect that the infinitesimally small amount of copper of one sixty-thousand millionth part of a gram in one litre of water exercises an appreciable influence. Now, there is no case in Metallurgy, so far as I am aware, in which a transformation is affected to such a degree; but, nevertheless, small quantities of different substances may exercise a very marked catalytic acceleration of the transformation of a metastable into a stable form. We shall meet with an example of this when we come to study the iron carbon alloys.

Let us pass on now to the consideration of the conditions for equilibria when we have got two substances. In this case we shall find that much valuable information as to the nature of the solid which separates out from a molten mixture of metals can be obtained from a study of the freezing point curves of the mixtures.

When we apply the Phase Rule to systems of two components, we find that there are not only two but three variable factors to be taken into account. Thus we may not only alter the pressure and the temperature, but also the composition of the system. If, therefore, we have two components existing in two phases, the system will be bivariant ($F = 2 + 2 - 2 = 2$); but as we shall in all cases consider the equilibria under atmospheric pressure, one of the variables is fixed for us, and so the system now becomes univariant. That is to say, if we have a system of two components existing under a definite constant pressure, then if we fix the composition of the system, the temperature of equilibrium will also be fixed. The system is therefore now univariant. The equilibrium between a solid and a liquid phase under these conditions will therefore be represented by a curve. When there are three phases, *e.g.*, two solid and one liquid, then the system becomes invariant (since the pressure is fixed). Consequently such a system can exist only at one particular temperature and when the mixture has a definite composition.

Let us now see what sort of curves we get when we determine the freezing points of mixtures of two substances. We have got various classes to distinguish here, namely:—(1) No combination takes place between the two components. (2) The components can form definite compounds. (3) The components separate out in the form of solid solution.

1. If we represent graphically the freezing points of mixtures of different composition, we shall obtain in the first case a diagram consisting of two curves cutting each other at a point, as shown in Fig. 3.

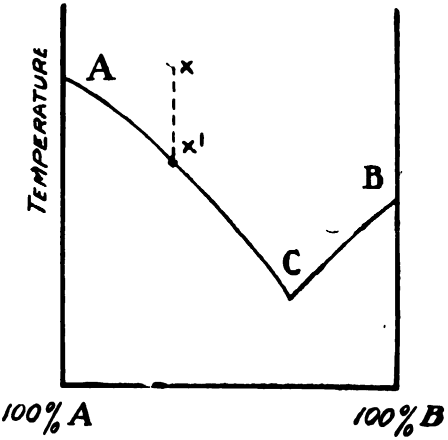

FIG. 3.

The point A represents the melting point or freezing point of one of the components, B the freezing point of the second component. Suppose, now, we start with a molten mixture of A and B represented by the point x. On cooling this mixture we find that its freezing point is lower than that of pure A, just as the freezing point of sea-water is lower than that of fresh water. Further, just as pure ice separates out from sea-water. and not a mixture of ice and salt, so in the case we are considering, pure A separates out at a temperature corresponding with the point x^1. Since pure A separates out, the composition of the molten mixture changes and the freezing point therefore continually falls, until when the composition of the liquid mixture has reached that represented by the point C, B also begins to be deposited and the temperature remains constant. From this moment onwards we have now three phases, two solid phases and one liquid phase, and consequently the system is invariant (constant pressure assumed). That is to say, A and B can crystallise out together only when the liquid has a definite composition and only at one particular temperature.

Similarly, if we cool down a mixture the composition of which is represented by a point to the right of C, pure B will crystallise out when the temperature has fallen to a point on the curve B C, and the freezing point will gradually fall until again the point C is reached, when the freezing point becomes constant. C is the lowest point at which solid and liquid can co-exist. It must be borne in mind that although a mixture of A and B in the proportions represented by the point C freezes at constant temperature like a pure substance, the solid which separates out is a mixture, or conglomerate, of A and B; *i.e.*, it consists of two solid phases. Since this mixture has a lower melting point than either pure A or pure B, it is called a *eutectic mixture*, and the point C is called the eutectic point.

Now, several alloys behave in the way described. Thus, zinc and cadmium, zinc and aluminium, copper and silver, tin and zinc, etc. In all these cases we obtain two freezing point curves cutting at a eutectic point, showing that these different pairs of substances do not form compounds with each other.

When we examine the cooling curve of mixtures we get a slightly different type of curve from that given by a pure substance. Such a cooling curve is shown in Fig. 4.

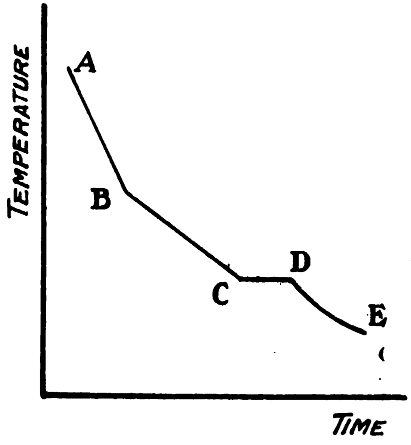

FIG. 4.

So long as the mass is entirely molten the temperature falls fairly uniformly (*ab*), but when the solid phase begins to separate out (at *b*) there is a certain amount of heat given out by the substance (latent heat of fusion), and so the rate of cooling becomes slower, as represented by *b c*. At *b*, therefore, the curve exhibits a "break" or sudden change in direction. When the eutectic point is reached the temperature remains constant, until all the liquid has solidified (*c d*), after which the fall of temperature again sets in. We have therefore two arrests on the cooling curve, viz., *b* and *c*. Here again the definiteness of the arrests depends on the rate of cooling.

2. The second case we have to consider is where the two metals can form one or more compounds. In this case there will be obtained not only the freezing point curves of the pure metals, but each compound formed will have its own freezing-point curve. If the compound has a definite melting point—that is, if it can exist in contact with a molten mixture of the same composition – then the freezing-point curve exhibits a maximum corresponding with the freezing point of the compound. This is seen in the case of the amalgam of mercury and thallium (Fig. 5), and also in the case of other pairs of metals. The right and left hand curves represent the compositions of mixtures from which the pure metals separate out; the intermediate curve, those from which the compound separates out. The summit of this curve gives the composition of the compound and the temperature at which it freezes.

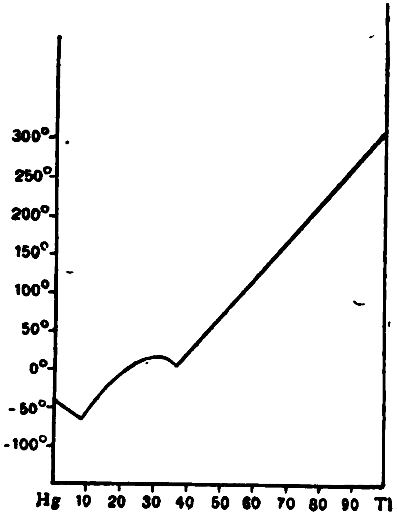

Fig 5.

From the diagram we see there are two eutectic points, one at which we have solid mercury along with the solid compound, the other at which we have thallium and the compound co-existing.

If more than one compound is formed, then for each compound we shall have a separate curve similar to the intermediate curve in Fig 5. Such a compound curve is given in the case of gold and aluminium.

3. There is a third possibility, namely, the metals do not separate out in a pure state, but form solid solutions, that is, the two components crystallise out together as a homogeneous solid phase.

Before going further, it will repay us to consider very briefly the behaviour which is found in the simplest case of two liquids which mix with each other. In this case we may have complete miscibility or only partial miscibility. Only the latter case is of interest for us at present.

If a small quantity of phenol (carbolic acid) is shaken with water, it passes into solution, but on increasing the quantity of phenol a point is reached at which there is a separation into two layers—one consisting of phenol saturated with water, the other of water saturated with phenol. As the temperature is raised the solubility of the phenol in the water and of the water in phenol increases, and ultimately at 68·4° the phenol and water become miscible with each other in all proportions. These relations are represented by Fig. 6.

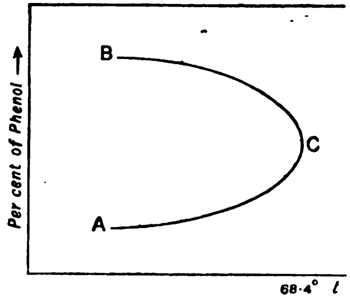

Fig 6.

Now just as we find that some pairs of liquids are miscible with each other in all proportions, while other pairs of liquids are only partially miscible, so also we find that some pairs of solids are completely miscible in the solid state, while others are only partially miscible.

If two substances are completely miscible in the solid state, then it is evident that there can never be more than one solid phase, the composition of which will, however, depend on the composition of the molten mixture from which it separates out. Our diagram therefore will show two curves, one referring to the solid solution, the other to the liquid solution. Since there can only be one solid phase, there can be no eutectic points, but the curves must be continuous. Three cases may be mentioned. 1. The freezing points of all mixtures lie between the freezing points of the pure components. The curves obtained in this case have the general form shown in Fig 7, No. 1. The dotted curve refers to the solid phase, and is called the melting point curve (or solidus curve). It represents the temperatures at which the different solid solutions commence to melt. The full-drawn curve refers to the liquid solutions and is called the freezing point curve (or liquidus curve). It represents the temperatures at which the different liquid solutions begin to freeze.

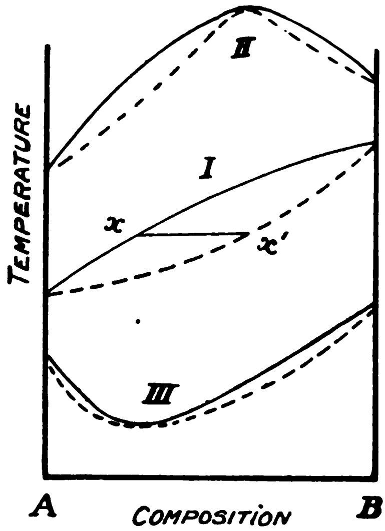

Fig 7.

When the liquid begins to freeze, the solid which separates out does not have the same composition; but the composition of the solid and liquid solutions, which are in equilibrium, is obtained by drawing a horizontal line, or line of constant temperature, *e.g.*, x x'. The point x' then represents the composition of the solid solution in equilibrium with a liquid solution of composition *x*. An example of the above type of curve is given by gold and silver which form an unbroken series of solid solutions.

With regard to the other two types of curves shown in Fig. 7, nothing need be said, except that at the maximum or minimum point, the composition of the solid solution and of the liquid solution become the same. The solid solution of the composition represented by the maximum or minimum point will melt and freeze again at constant temperature, like a pure compound.

Only a few cases are known, however, in which the two substances form a continuous series of solid solutions. In most cases only partial miscibility is found, so that a point is reached at which two mutually saturated solid solutions are obtained. When this is the case we have, of course, an invariant system, because we have now two solid phases—each of them a solid solution—and a liquid phase. The temperature and composition of the system at which these two mutually saturated solid solutions are formed will therefore be perfectly definite.

Two types are to be distinguished: (1) The freezing point curve exhibits a transition point. (2) The freezing point curve exhibits an eutectic point. The first type of curve is represented in Fig 8. In this case the freezing point of A is *raised* by addition of B, and from the liquid mixed crystals separate out. On further increasing the amount of B, a point is reached at which two solid solutions represented by D and E are formed.

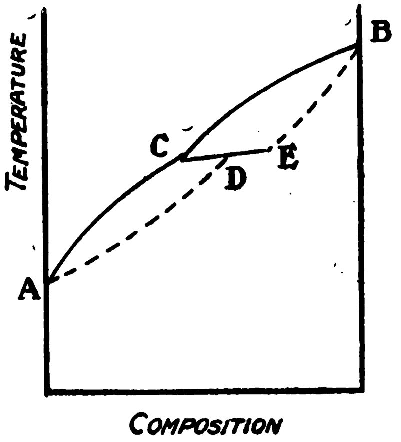

Fig 8.

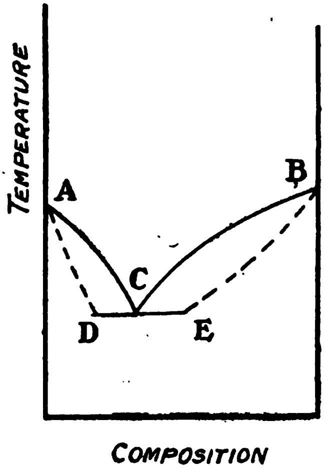

Fig 9.

In the case of the second type of curve we have an eutectic point, as represented in Fig. 9, the two solid phases being again solid solutions, the composition of which is represented by D and E.

A very good example of the formation of solid solutions is given by copper and zinc. From all molten mixtures of copper and zinc, only solid solutions of different composition separate out. This is shown in Fig. 10, which is only a part of the complete diagram, but sufficient to illustrate what I have been saying. From mixtures of copper and zinc

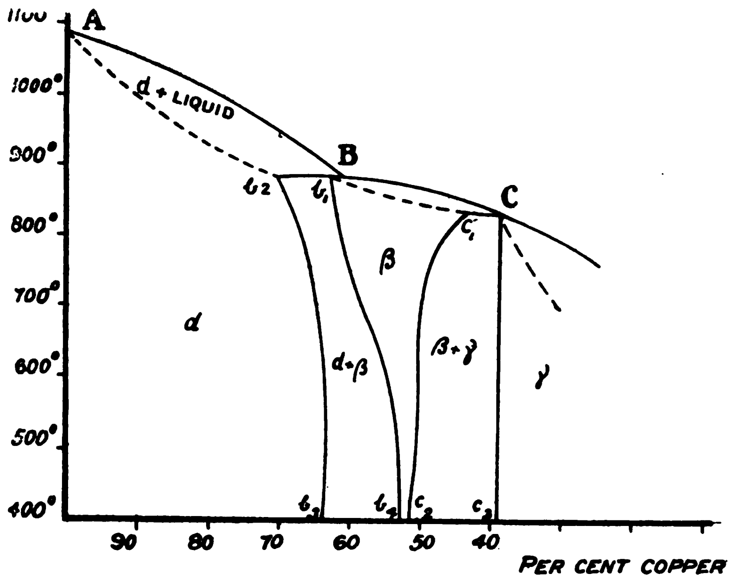

Fig 10.

the composition of which is represented by A B, solid solutions (Alpha solutions) will separate out. When the composition has reached that of point B, two solid solutions corresponding in composition with points b_1 and b_2 separate. From solutions still richer in zinc, Beta-solid solutions separate out, and then at point C, we have equilibrium between two solid solutions Beta and Gamma and liquid. And so on.

Another point of considerable importance which is also illustrated by the case of copper and zinc, is that the mutual solubility of two solid solutions undergoes change, just as we saw that the mutual solubility of phenol and water undergoes change with the temperature. This change in the composition of the saturated solid solutions b_1 and b_2, is represented by the curves b_1 b_4, and b_2 b_3. Similarly the composition of the saturated solid solutions b and c at different temperatures, is represented by $c.c_2$ and bc_3.

As an example of the formation of solid solutions showing an eutectic point, we may take finally the case of the iron-carbon alloys We shall also find in the discussion of these opportunity to refer to several of the points already mentioned.

First of all, with regard to iron itself, it is known to exist in three different allotropic modifications, called Alpha,-Beta. and Gamma-ferrite. Like the two different modifications of tin these different forms exhibit transition points at which the relative stability of the forms changes. Thus the transition point for Alpha-and Beta-ferrite is about 780°; and below this temperature the Alpha-form, and above it the Beta-form is stable For Beta-and Gamma-ferrite the transition point is about 870°, the Gamma-form being the stable modification above this temperature. Of these different forms of iron, only the Gamma-ferrite appears to have the property of dissolving carbon, and of thus giving rise to solid solutions of carbon in iron.

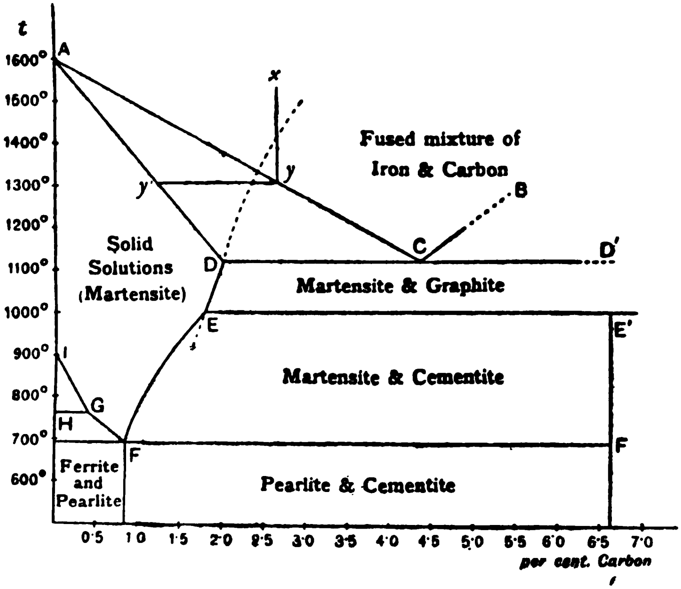

Fig 11.

The diagram given in Fig. 11, shows how the different systems of iron and carbon are related, and with the help of this diagram, which has, of course, been constructed by applying the Phase Rule to the data obtained by experiment, the behaviour of different mixtures under given conditions can be predicted. Although with regard to the main features of this diagram, the different areas to be mapped and the position of the frontier lines, there is general agreement, a final decision has not yet been reached with regard to the interpretation to be put on all the curves.

The curve AC represents the freezing point curve for mixtures from which solid solutions of the composition represented by AD separate out. Point C is an eutectic point, and mixtures of this composition deposit, on cooling, a solid solution of composition D (containing 2 per cent. of carbon), and practically pure carbon. The temperature of the eutectic point is 1,130°.

As we have already found, however, changes can take place below the solidification point, and the curve D E represents the change in the composition of this solid solution with the temperature. As the temperature falls below 1,130°, more and more graphite separates out until at E, when the temperature is 1,000°, the solid solution contains only 1·8 per cent. of carbon. Cementite also begins to separate out (the composition of which is represented by E' F'), and the composition of the solid solution undergoes alteration as represented by the curve E F. Below the temperature of the point F the martensite becomes heterogeneous and forms pearlite.

It has already been stated that iron exists in three allotropic modifications, the regions of stability of which are separated by definite transition points, represented in Fig. 11 by H and I. Since neither the Alpha- nor the Beta-ferrite dissolves carbon, the transition point will be unaffected by the addition of carbon, so that the transition curve HG is horizontal. In the case of Beta- and Gamma-ferrite, however, the latter dissolves carbon, and the transition point is consequently affected by the amount of carbon present. This is indicated by the line IG.

If a martensite containing less carbon than that represented by the point G is cooled down from a temperature of say 900°, then when the temperature has fallen to that represented by a point on the curve IG, Beta-ferrite will separate out, and, as the temperature falls, the composition of the solid solution will alter, as represented by IG. On passing below the temperature of HG, the Beta-ferrite will be converted into Alpha-ferrite, and as the temperature falls, the latter will separate out more and more, while the composition of the solid solution alters in the direction GF. On passing to still lower temperatures, the solid solution at F (0·8 per cent. of carbon) breaks up into pearlite. If the percentage of carbon in the original solid solution was between that represented by the points G and F, then on cooling down no Beta-ferrite but only Alpha-ferrite would separate out.

We see, therefore, that when martensite is allowed to cool slowly, it yields a heterogeneous mixture either of ferrite and pearlite or of pearlite and cementite. These heterogeneous mixtures constitute unhardened steels. If, however, the martensite (or solid solution of carbon in Gamma-ferrite) is rapidly cooled from a temperature above the curve IGFE to a temperature below this, the various changes just described have no time to take place, so that we get a homogeneous solid solution constituting hard steel. Evidently this is a metastable system, and corresponds with a super-cooled liquid, or with, say, white tin, below 20°.

The diagram given above is due essentially to Roozeboom, and is based on the conclusion that at temperatures below 1,000° the stable systems are martensite and cementite, or ferrite and cementite, while graphite is metastable. More recent work, however, goes to show with practical certainty that Roozeboom's conclusion in the latter respect is wrong, and that the stable system at low temperatures is ferrite plus graphite. All the curves, therefore, below DD^1 do not refer to stable equilibria, but to metastable. Now we have repeatedly seen that metastable systems may exhibit great permanency, and so it is also in the case of these systems containing cementite. Although, on allowing a molten mixture of iron and carbon, containing, say, from 2 to 4·3 per cent. of carbon, to solidify, we ought to get the stable system ferrite and graphite, we obtain under certain conditions, *e.g.*, rapid cooling or in presence of manganese, the metastable substance cementite. This primary separation of a less stable phase is not at all an exceptional behaviour; in fact, it is rather the rule. That is to say, we find that when a system undergoes change, it is not the most stable but a less stable form that is produced first, and the less stable then passes with greater or less velocity into the more stable form. Thus on allowing sulphur to crystallise from solution we find that the monoclinic form frequently forms, although it is the rhombic form which is stable at ordinary temperatures; or again, if mercuric iodide is precipitated from solution, the yellow form first separates out and then changes into the more stable red variety, and so on. The primary separation of the less stable cementite is therefore a perfectly normal occurrence. In time, however, this cementite must break up into ferrite and graphite, which are the stable forms, but this change may take place with great slowness, especially at low temperatures. On allowing the cooling to take place very slowly, however, time is given to the cementite to pass into the more stable forms, and so with very slow cooling graphite is obtained.

We have already seen in the case of tin, that the transformation of the less stable into the more stable form can be accelerated by catalytic agents, and this we find also in the case of the transformation of cementite. Thus in the presence of small quantities of silicon, which acts as a catalytic agent in accelerating the change, cementite changes into ferrite and graphite. On the other hand we can also have what are called negative catalytic agents, *i.e.*, substances which retard change. Such a negative catalytic agent we find in manganese, the presence of which retards the change of cementite, and therefore promotes the production and permanence of the less stable system.

Such then are a few of the physico-chemical principles which have an important bearing on the problems of metallurgy. I have not sought to enter on the discussion of different metallurgical investigations in detail, for neither the time nor my knowledge of these investigations would permit of it. I have endeavoured merely to give you a glimpse into a portion of pure science which profoundly influences the interpretation and understanding of many of the experimental facts of metallurgy, and which is of value also in suggesting new directions of investigation.

Time has not allowed of my entering on another important branch of physical chemistry, namely, electro-chemistry, which is now of so much importance both for the production and the purification of metals; but sufficient has, I hope, been said to stimulate a greater interest in the advances made in pure science, and to encourage a deeper and more serious study of physical chemistry, the importance of which has, I trust, been sufficiently indicated this evening.

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THE DISCUSSION.

Professor Turner: We are deeply indebted to Dr. Findlay for the trouble he has taken in preparing this paper, and bringing before us in so plain, simple, and well arranged a manner, the fundamental facts of such an important subject. Some ot us are old enough to remember the earlier days of this Institute when the members could be roughly divided into those who knew something of chemistry and those who did not, and there was therefore a distinct difference in the way which the members attacked chemical problems. Since that time enormous developments have taken place in connection with the scientific aspects of the metallurgy of iron and steel, and now we have rather to divide men into those who are able to understand the language of the physicist, and to speak in the language of modern chemical terms, and the other class of men who may be able to use chemical formula but are not in touch with the latest phases of physical thought. It is rather sad for us to find that just when the world is reaping so much benefit from the great work of Gibbs and Roozeboom—who was the exponent of Gibbs's original idea—I say it is sad that these have passed away when we are just beginning to fully realise the benefit which their work has conferred upon us. All who have kept abreast of modern technical literature will see the extremely important part which has been taken by papers on pyrometric applications in connection with the work of Roberts-Austen. Then we had the microscopic work, started by Sorby and brought to perfection by Osmond We have also the introduction of the allotropic theory by Osmond based upon the pyrometer and the microscope, and then within the last few years we have seen the applications of the phase rule, particularly by Roozeboom, who had at his disposal the work of Roberts-Austen, apart from which the diagram on page 94 of this paper could not have been prepared. One has only to look through the paper to see how very important these principles are, because we see that they apply to some of the most fundamental of the processes, and of the alloys, which are used by metallurgists. On page 87, fig. 3, the diagram there gives us the reason for cupellation, the explanation of the separation of silver from lead. In fig. 5 we have a diagram which corresponds with what takes place in the chief series of bronzes. In fig.
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10 we have the brasses and the zinc and copper series, and, indeed, in that diagram we have practically the whole of the useful alloys in that series. The facts represented in that diagram underlie practically all the processes of the Birmingham brass trade. And then, last but by no means least, we have the diagram, page 94 (fig. 11) showing the iron carbon series, which explains the whole of the heat treatment of iron, mild steel, high carbon steel, and of cast iron, the whole of the series of iron and steel, other than special steels. And with special steels we only require a modification of the diagram in accordance with special principles. Some of the illustrations represent parts of diagrams and in other cases the whole of the diagram has been made out. I will just note two little points which I think might be altered in the revised copy. On page 95 it is said, "These heterogeneous mixtures constitute soft steels." I think it would be better to say "unhardened" steels instead of "soft." And further, on page 95, it reads: "more recent work, however, goes to show with practical certainty that Roozeboom's conclusion is wrong. and that the stable system at low temperatures is ferrite plus graphite." Dr. Findlay, I am sure, does not mean that Roozeboom's conclusion as whole is wrong. It would be better to say "on the point" after the word "conclusion." At the last meeting of the Iron and Steel Institute papers on this subject by various writers were discussed, including one principally by Benedicks. Any who are specially interested in diagram fig. 11 should see the diagram of Benedicks, which, I think, gives us the fullest and most correct interpretation of the equilibrium of iron and carbon in steels. In conclusion I feel that we are all very much obliged to Dr. Findlay for his paper.

Mr. J. E. Fletcher: I should like with your permission to take at any rate some little part in this discussion, which has been so ably opened by Professor Turner. I think with him that we should keep ourselves acquainted with the thoughts which are occupying the greatest minds in what we may call the higher walks of metallurgical science, and that we should recognise the importance of what we had heard to-night in connection with our own industries in this district. I think every student of metallurgy to-day should be thoroughly well grounded in the knowledge of the principles we have had put before us to-night. When we think how little we know at present of what is going on underneath that mysterious slag and metal change, or series of changes, in the blast furnace, the puddling furnace, and the Siemens-Martin furnace, we realise how little knowledge we really yet possess. I think those who have read the papers contributed of late to the various metallurgical bodies, and more particularly to the Iron and Steel Institute, will be struck with the immense possibilities there are of further knowledge. We think, for instance, we know much about silicon and manganese in slags, but how little we really know of how silicon and manganese got there. I believe Professor Turner has done some considerable work in connection with the temperature and composition of blast furnace slags When we know more of this, then we shall understand better what to expect in connection with metallurgical processes. Such knowledge is very much more necessary than it has been in the past. We are coming to a time when we shall have to put up more and more with impure ores, and our pig iron fractures do not tell the tale they used to, so we are almost obliged to know something more of the chemistry of our work than formerly. The work of such men as Fondrier is becoming increasingly important. His curves are very helpful to us in trying to learn more about these mysterious actions. I hope we shall not for long have to rest under the stigma of a want of knowledge of scientific facts. Depend upon it, if we are content to remain ignorant of them, we shall, as a district, suffer, because we shall find that our processes in the future will have to be determined more and more by a close knowledge of these subjects We only need to look at the work of the last 2 or 3 years in connection with self-hardening or high-speed steel, to see what the advantage of such work as Dr. Carpenter's has been in connection with the satisfactory production of tool steels and the regularity of their manufacture to-day.

Mr. H. T. Pinnock was very much interested in respect to the burning of limestone, which process afforded a very good illustration of the phase rule. In limestone burning, the calcium carbonate splits up into lime and carbon dioxide. Here, theoretically, according to the phase rule we have a case of complete heterogeneous equilibrium, for the substances are CaO and CO_2 and the phases are CaO, $CaCO_3$, and CO_2. Practice confirms this, for it is found that the concentration of the gaseous phases (*i.e.*, the dissociation tension of the CO_2) at a given temperature is constant, and therefore independent of the amount of each phase. Complete decomposition into lime and CO_2 can only occur therefore, when the gaseous phase is removed (as in lime burning), or when its tension is kept below the dissociation tension. If, however, the tension of CO_2 is above the dissociation tension, limestone cannot be decomposed at all, and under these circumstances it is possible to fuse it when on solidifying it assumes a crystallein structure and becomes marble. Dr. Findlay's remarks about the transition of grey into white tin and the reverse recall the behaviour of certain crystals in what is known as "weathering." It is found that a perfectly sound crystal does not weather, but that when weathering starts at any point it spreads over the whole crystal. This behaviour can, I think, be satisfactorily explained by the phase rule. A simple example is that of the Glauber's salt $Na_2 SO_4$ 10aq. We have in this salt two substances $Na_2 SO_4$ and H_2O; in the case of a perfectly sound crystal exposed to the air, there are only two phases, $Na_2 SO_4$ 10aq and H_2O (moisture of air). According to the equation given by Dr. Findlay there are still in this system two degress of freedom,

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i.e., the pressure of water vapour and temperature can both be selected arbitrarily (within certain limits). If, however, some weathered crystal be present, the number of phases is three; then there is only one degree of freedom, or in other words, every temperature has only one corresponding pressure and inversely every pressure only one temperature; so that any departure from the equilibrium curve brings about the disappearance of one of the phases. This, I believe, is the explanation of many cases of disintegration of the face of stone buildings, etc.

Mr. O. F. HUDSON: I think Dr. Findlay's paper is one which should not only be read but very carefully studied. For all those who have to deal with iron and steel the diagrams given in Fig. 11 on page 94 should be taken as a guide. But I think in some respects that diagram is not complete, or not as complete as it might be, especially in the high carbon series (that is, cast iron) particularly with reference to the influence exerted by other impurities. I can cordially support all Dr. Findlay's arguments and think he has proved to-night that the subject of physical chemistry is not only of great theoretical importance but of the utmost practical importance as well.

Mr. THOS. ASHTON: I happen to be one of those who do not belong to the scientific world, yet I have had sufficient insight into chemistry and metallurgy to see its most facinating side. If Dr. Findlay and Professor Turner would only come down from their pedestals and make the subject a little more intelligible to ordinary mortals it would be a great advantage. I think we are introduced into a new sphere by this paper, and I can see that the application of its principles to practical iron and steel manufacture would be advantageous. If this law could be set out in more familiar terms it would be a good thing. We cannot all speak in scientific language, but yet have sufficient interest in the subject to desire to pursue it further and see how we can apply it to our every day practice. I hope we shall be able to apply it.

The PRESIDENT proposed a vote of thanks to Dr. Findlay.

Mr. W. BROOKS seconded, and the resolution was carried unanimously.

DR. FINDLAY replied on the discussion. In the course of his remarks he said: It has been a very great pleasure to me to come here, and I can assure you that the advantage which accrues from the mingling of the practical and theoretical sides of metallurgy is mutual, and is of as much benefit to the academic side as to the industrial. I have to thank Professor Turner for the strong support which he has given to my argument as to the need for greater attention to scientific study. As I intimated in my paper, the reconciliation between pure and applied science is fraught with advantage to all. In this country scientific study has not received as much attention as in Germany and the United States, and I consider it my duty to do what I can to advance the knowledge of physical chemistry, for I believe it is of the utmost importance in works practice. With regard to the analogy between tin and lime burning, one of the speakers was perfectly right. With regard to the salts. I don't think I quite understood him. One would expect that hydrated crystals would pass into an anhydrous form. In undamaged crystals that is found not to be the case, but if you damage the crystal you find it does. That case is analogous with tin and limestone burning. We are in all cases dealing there with transition processes and with univariant systems. As we alter temperature we alter also the pressure. I thank you again, gentlemen, for the attention you have given me to-night, and also for the vote of thanks.

This concluded the proceedings.

The Sixth Meeting of the Session was held at The Institute, Dudley, on Saturday, March 23rd, 1907.

The Chair was taken by Mr. Buchanan (vice-President of the Institute).

The Minutes of the last Meeting were read, approved and signed, and Mr. Albert E. Honour was elected a member of The Institute.

The vice-President regretted to say that Mr. E. G. Izod, having a very bad cold, was unable to be with them; his assistant, Mr. F. Noel, had come forward to fill the gap, and would, he had no doubt, do credit to the occasion, since he had been for a number of years at work with Mr. Izod, and was thoroughly acquainted with the subject.

Mr. Noel then proceeded to give his paper, which was illustrated with numerous views. A *resumé* is appended :—

SOME APPLICATIONS OF THE STEAM TURBINE.

By F. NOEL.

Mr. Noel observed that he was afraid he could not do the paper the same justice as Mr. Izod would have done, as Mr. Izod was one of the best authorities on the Steam Turbine.

They would notice that the heading of the paper was "Some applications of the Steam Turbine," which was somewhat different from a paper on the Turbine itself, which he remarked he would have to more or less confine himself to, as he had had only a few hours' notice in which to collect notes, etc., for the lecture.

The Turbine at the present time is applied to some half dozen different functions, one of the most important being that of driving electrical generators for various purposes.

The Parsons type of turbine had, in England, at any rate, taken premier place among prime movers of this type. When Mr. Parsons started work on the design of the steam turbine he took a rather different line from other inventors, in that he used all his experiments and work in reducing the number of revolutions of his machine by increasing the number or rows of fixed and moving blades instead of only using a single row as DeLaval, with the consequent high blade speeds.

In 1884 Parsons brought out his first commercial turbine. It ran for several years driving a 10 h.p. dynamo at 18,000 revolutions per minute. The trial which brought the turbine first to public notice took place at Cambridge in November, 1892. At that time it must be remembered that the units in power stations were far smaller than at present, and therefore the Turbine could not show itself to its full advantage.

The view of an impulse turbine wheel was now put on the screen, showing the steam flowing from the nozzles and through the blades. From this slide the lecturer explained the action of the steam flowing through the fixed and moving blades of a Parsons type turbine.

The next slide showed a section through a DeLaval wheel, which is constructed to withstand the great stresses set up by the extreme velocities used in this type of turbine. A 6 h.p. turbine runs at 30,000 R.P.M., while in a 30 h.p. type the R.P.M. are only reduced to 10,000.

Figure 4 showed a section through a turbine, and it was again pointed out how the steam expands on its way through the blading. The idea of having stages of different diameters in the turbine was so that the large areas required to pass the steam at the L P. end did not cause the blades to become of excessive length. The usual practice was to have three stages, but at least one English firm use four.

The next view (a diagram) showed a graphic representation of steam expanding through a turbine, taking out a small amount of work at each row of blades. The pressure being shown in lbs. per square inch and corresponding volumes in cubic feet. In a reciprocating engine it was explained that it was impossible to design a L.P. cylinder to accommodate the huge volumes at low vacuum. While were this possible, considerable condensation would take place when the live steam came in contact with the cylinder walls which had just been exhausting steam at a very low temperature. The pressure drop at each row of a Parsons type turbine being so small, gave a low steam velocity which enabled turbines of this type to be used at a comparatively low speed.

The next view represented a section through a Willans turbine. The turbine was supported at each end, the high pressure end being free to move in grooves in order to take up expansion. The steam balance pistons were explained, and it was stated that the shaft, having no end thrust at all, could be seen to move slightly when under steam.

The next side was a general view of the turbine last shown. This was followed by a slide showing the steam end of a turbine, illustrating the governor gear, oil pump drive, etc., etc.

A view was shown of a turbine driving a tandem set of two direct current machines, each of 750 K.W., at Glasgow. The condenser plant, pump, motors, etc , were seen below the turbine.

A sketch was next presented of the arrangement of turbines driving generators, supplying power for working steel rail rolling machinery at the McKenna Mills. The process is for re-rolling rails to a smaller standard, or re-rolling worn rails. These turbines are employed, each driving a 750 K.W. Siemens generator. This plant has been running between two and three years, and these sets have never given any trouble from blade fouling since first starting up.

The next view was that of a turbo-generator used at a cotton mill close to Manchester. This plant had not been running very long, and in a short report read, the users said that the data they gave, being only taken from the few months' use of the plant, could only be looked upon as approximate. The costs were working out about ·13d per unit for labour, oil, etc., which, together with ·10d. for interest, depreciation, etc., made up a total cost of ·23d. per unit.

In connection with the advantage of electric driving in textile and other mills, many enquiries had been made as to the results obtained with that system of driving in this country, and the result was that owners and users alike find it a most satisfactory method. One important advantage with an electric drive is the ease of registering and checking the power taken by the different machines and processes throughout a mill.

In some cases where steam turbines driving generators had superseded reciprocating engines, there had been great saving of space in the engine room. In one case an old engine of the beam type of 1,100 h.p. which occupied a floor space of 1,040 square feet, weighing 100 tons and requiring an engine room of 40,000 cubic feet, was replaced by a turbine capable of taking 50% more load, running at 1,500 R.P.M. This turbine and generator only covered 960 square feet, and an engine room of 24,500 cubic feet, in fact, not much more than half that of the beam engine.

The steam turbine has, of course, been used for the direct driving of other plant beside generators, but owing to the fact, that to be efficient, turbines must run at high speeds, pumps and blowers ranked next in importance to the generators.

A photo was then shown of a turbine driven pump for Sydney. This machine ran at 3,300 R.P.M. These pumps are capable of raising 1¼ million gallons per 24 hours to a height of 750 feet. The consumption on trial being 28lbs. of steam per horse power.

Turbine pumps are also being used for boiler feed pumps. At the St. Denis Power Station in Paris they have three reciprocating pumps besides other types, and one turbine pump, and Mr. Noel said that the people in charge preferred the turbine pump to any of the others. The turbine pump runs at 1,500 R.P.M., and has so far given no trouble. This type of pump takes up very much less space than the ordinary force pump, and the initial cost is appreciably less than that of a reciprocating pump.

An exhauster fan was next shown, followed by a turbine blower, and afterwards by a turbine compressor capable of delivering air up to 80lbs. per square inch pressure.

Two rings of blades were next shown as built by Messrs. Willans and Robinson, of Rugby. This type is unlike that of Messrs. Parsons, in that the Willans blading has a shrouding over the blades, and that the blades are built up into half rings (being held between the shrouding and foundation ring) before being fixed in the turbine; while in the Parsons type each blade is placed and fixed in position separately, a small caulking piece acting as distance piece to hold the blades in the required position.

Several machine tools were next shown for carrying out the various operations required to form a Willans Blade ring. First came a press for stamping the root on the bottom of the blade, to enable the blade to be slipped into the foundation ring, giving the correct angle, etc.

Next was shown the foundation ring cutting machine for dividing up the foundation ring to receive the blades. While in the next view appeared the machine for punching the shrouding strip to receive the tip of the blades, and into which they are rivetted. Both the last machines work with great accuracy, ensuring the equal and correct spacing of the blades.

A slide followed showing a half ring of blades being caulked into the body of a Willans turbine.

A rotor was next put on of a 3,000 K.W. set running at 750 R.P M· A good many people (observed Mr. Noel) are still rather shy of steam turbines, but this rotor had now been running for 18 months in a turbine in Glasgow, and had not cost a penny in repairs. In fact five of this type were running in that town with every success. These rotors were generally made of cast steel.

A view of the same rotor was then shown, finished blading, and having the shrouding turned up to give the required clearances.

The Lecturer next dwelt on the question of costs, and without any names being given, two sets of prices for the same electric generating plant were given, the reciprocating plant coming out at nearly double the cost of the turbine plant, the two estimates being the highest and lowest for a large contract.

A diagram was next shown correcting consumptions of steam and revolutions per minute. It was stated that a fundamental formula in turbine work was that the square of the speed of the blades (in feet per second) multiplied by the number of rows of blades was approximately a constant, upon which the efficiency depended, therefore as the revolutions dropped the consumption rises unless it is possible in some way to add to the number of rows of blades. There was only one branch of turbine machinery in which this was done, and that was in naval vessels. The naval ships had to have two economical speeds, full speed and cruising. For the former one set of turbines would be sufficient, for the latter (since the R.P M. had to drop with the vessel's speed) it was found necessary to put on extra rows of blades, and this was done by passing the steam through an extra turbine, or turbines, and exhausting from these into the full speed turbines. It could be readily understood that this corresponded to adding extra rows to an ordinary turbine. In merchant vessels and cross channel steamers these extra turbines were not needed, as these classes of vessels maintain practically the same speed the whole time they are at sea.

A view of a marine turbine cylinder was next shown, with the steam gland packing to prevent leakage of steam. This was composed of strips of metal in the casing and on the rotor with such clearances as to allow the rotor to turn without the strips touching. The steam is prevented from leaking by being throttled as it crosses a strip and then expanding between the strips.

A picture of the famous little "Turbinia" was now shown and was referred to as the real beginning of serious turbine development, at any rate for marine work, if not universally. This vessel was first brought to public notice at the review in 1897. Her displacement was 44 tons, her length 100 feet. She steamed, when at full speed, about 40 miles per hour, which was at that time a record at sea by a large margin. Several different arrangements and types of turbines were tried in the Turbinia, together with various arrangements of propellors and shafts.

A picture of the "Carmania" was next shown. This vessel was built in 1905, her turbines developing 21,000 h p. During the first year of regular running her turbines were not opened up even for inspection once, which considering the newness of this type of machinery marks its reliability very strongly.

Several views and diagrams of torpedo boat destroyers were then shown, and the various arrangements of shafts and propellors were pointed out.

The next slide showed the reversing or astern turbine built into the same case as the L.P. turbine on the Carmania. The reasons for this are to economise space, and to allow the reversing turbine to revolve in vacuum, when going ahead, in order to reduce the wind friction.

The Lecturer, in conclusion, observed that the marine turbine had made great strides in the last year, both in development and in popularity, and it was satisfactory to think that in this England was giving a lead to other countries. That was all he had to say, but if there were any questions he should be pleased to answer them, or if there were enquiries which needed consideration he should be very pleased to reply to them by post.

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THE DISCUSSION.

The **Chairman** remarked that the members had an opportunity now of asking Mr. Noel any questions, and he hoped that there would be a good discussion upon so interesting a subject.

Mr. W. H. **Carder** asked if the Lecturer would give them the price of steam turbines suitable for blast furnace work, and what amount of blast could be delivered into the furnace per horse power developed by the turbine. Also what would be the steam consumption of a turbine for working a rolling mill.

Mr. **Noel**: Would the latter be with an electric drive?

Mr. **Carder**: I don't know. There are very few installations in this district which would require more than 250 h.p. to one set of rolls. The larger engines may be left out of consideration. The majority of mills in this part of the country are rather small, and I don't think that the total horse power required for an ordinary merchant mill would exceed 400 h.p. in all. It would be some guide to the members of the Institute if they were to know the relative cost and efficiency of a turbine suitable for driving a mill of that description.

The **Chairman**: I should be glad if Mr. Noel would explain if there, are any difficulties in regulating the speed from 1,500 to 800 revolutions per minute.

Mr. **Carder**: The point is are there any difficulties, and, if so, what are they, in reducing the enormous speeds at which turbines run, down to a small number of revolutions. You may have one set of rolls running at 80 R.P.M. and other sets at three times that speed. It is necessary therefore to be able readily to regulate the speed. What are the difficulties which will prevent turbines being reduced from a high speed to a lower one, say from 3,000 to 150?

Mr. **Noel**: Is there any reason why you should not use gearing?

Mr. **Carder**: Gearing down means losing a large amount of power. If you have to gear down from 3,000 to say 300, what will be the loss of power per brake horse on the 300 R.P.M. shaft?

Mr. **Noel**: It would be impossible to build a turbine for a great variation of revolutions, as the machine when being used at a low number of R.P.M. would be very inefficient, and would be unable to pass the required amount of steam. If an electric drive was used, a turbine generator of 250 to 300 K.W. output would take approximately 21lbs. of steam per K.W. (15·65 lbs. per h.p.) hour using 150 degrees Fahr. superheat and 28in. vacuum.

The efficiency of gearing for heavy work, if reducing 100 h.p. from a 3,000 to 150 R.P.M. shaft may be roughly taken as 83%, a well balanced gear might, however, be taken nearer 90%.

A good many turbine blowers at present in use, capable of delivering 20,000 cubic feet per minute and taking a 50% overload, are being used in various ironworks. Turbo exhausters are also in use, some exhausting 28,000 cubic feet of air against 28in., and delivering against 8in. pressure.

Mr. **Carder**: That, of course, is very small. At a modern blast furnace we blow at anything from 4lbs. The lowest pressures I am acquainted with are 4½ or 5lbs. and they are being used up to 8, 10, and 15 lbs. per square inch in this district. I have not been able up to the present to get the steam consumption of turbines per horse power so as to make a comparison with the ordinary steam engine. Apart from the comparison of capital involved, everyone will want to know, in considering the claims of one against the other, what is the amount of steam each class of engine consumes.

Mr. Noel : A Turbo blower running at 3,000 R.P.M. with 160lbs. of steam at the stop valve, and 27in. vacuum (barometer 30in.) when delivering against a blast pressure of 10lbs. per square inch, delivered 73 cubic feet of free air per lb. of steam consumed. The total amount of free air inhaled by the plant was 18,500 cubic feet per minute, and the total steam consumption was 15,000lbs. per hour. At 3,600 R.P.M. the same plant delivered 18% more air, at 14lbs. per square inch blast pressure.

Mr. E. A. Dowson : I have taken a great deal of interest in high pressure steam, and should like to know whether this turbine blade ring, which has been handed round for inspection, is a real one or only a model, as I notice that the blades are loose.

Mr. Noel : The half ring of blades is a working ring, but the blades are never fixed tight in either top or bottom strips till the blade ring is actually placed in the turbine. The lower strip goes into a groove in the rotor or casing of the turbine, the groove being dovetailed and broad enough to allow of a thin metal strip being inserted alongside the bottom strip of the blade ring. This thin strip is then caulked down, filling the groove completely, and holding the blades tight against the side of the groove so firmly that it is an impossibility for them to come out owing to centrifugal force. One ⅛in. blade pulls out at about 1,700 lbs., while the other sizes ¼in., ⅜in., and ⅝in. bear the same pull in comparison to their cross section.

Mr. Dowson : The channel which I see on the other side is, I suppose, for steam packing ?

Mr. Noel : Yes, partly. The groove into which the bottom strip (foundation ring) fits is not as deep as the foundation ring, so that the bottom stands above the level of the rotor or casing. The channel strip is the same depth, as the foundation strip stands out, so that any leaking steam has an irregular path, constantly being throttled and subject to eddy currents. The leakage is also proportionate to the drop of pressure across the row of blades. Now with the channel strip we have an intermediate pressure which halves the drop, and, therefore, the leakage. The channel also provided protection in case of accident, and held the blade tips in correct place to give required opening, angles, etc.

Mr. F. Somers : How would a steam turbine answer for driving a 150 h.p. crane ?

Mr. Noel : Electrically ?

Mr. Somers : Yes.

Mr. Noel: The consumption would be as good with the reciprocating engine of this size if not better than the turbine, also with the turbine a condenser would be necessary to get good results. As to governing, the turbine would be perfectly steady with any changes of load with correctly set governors. In the McKenna Rolling Mills, which I mentioned before, the governing is within 2% (running at 1,500 R.P.M.)

Mr. Somers: We are governing within 2% with our crane engine.

Mr. Noel: Then in this case there is not much advantage in favour of the turbine, unless economy of space is wanted.

Mr. Samuel Moore: I should like to ask how turbines can be used in conjunction with reciprocating engines.

Mr. Noel: Turbines are used to make use of the exhaust steam from reciprocating engines. When engines exhaust into the air you are wasting as much power as you are using. The method is to place a turbine between the engines (of any sort, either electric light, rolling engines, etc., etc.), and a condenser, so that the steam passes through the turbine to the condenser. In this way a very large amount of otherwise waste heat is turned to good account. As an example, a steel works using 32,000lbs. of steam per hour put in exhaust turbines, which resulted in the production, and therefore the saving, of one horse power for every 30 lbs. of steam passed, or a total extra output, without increase in boilers, of 1,000 h p., using a 28in. vacuum in the condenser. A difficulty presents itself with application to engines where exhaust is irregular, while the turbine requires a continuous supply. In this case the engine exhausts into an "accumulator." This consists of a form of boiler shell, and contains water with (in the simplest form) an arrangement of cast-iron bars or pans. When steam enters the accumulator the cast-iron will absorb heat and cause condensation of a certain quantity of steam. Owing to this, heat accumulates when steam enters the accumulator, and a rise in temperature follows, such steam as is not condensed causing a rise in pressure. When the supply ceases, the demand from the turbine decreases the pressure, and the latent heat of the steam held by the cast iron and water serves to vapourise a given weight of water, and the flow of steam to the turbine is maintained constant.

Large savings have been made by inserting turbines between engines and condensers, even when the engines have been previously used condensing.

At one station this was done, with the result that a clear gain of 37% more output was obtained. The total expenses being only for the turbine and generator, the old condenser (from the reciprocating engine) being used. No extra hands were employed, and no extra boilers, etc., had to be put down, so that the changes on this plant were very small, more especially as the depreciation on turbines is less than with the *reciprocating type* of engine. This exhaust turbine could be used by itself with high pressure steam if the engine broke down, by use of a reducing valve, or if the turbine broke down, the engine could exhaust direct to the condensers by a byepass round the turbine, which gives several standbyes in case of accident.

The VICE-PRESIDENT: I think we shall carry away with us to-night a much clearer view of the steam turbine, and its construction, than many of us have had previously. This country, no doubt, owes a great deal to the ingenuity and ability of Mr. Parsons in making the first successful steam turbine for marine use, which you have seen to-night on the screen. The turbine has been wanted for years past, and it is within my knowledge that Murdock, who you will remember was associated with James Watt, made a small one, and a man I know came across it amongst a lot of rubbish at Murdock's house. Murdock's name was on it, so there could be no doubt as to its genuineness. They took this old model to pieces, cleaned it up, put steam it, and it rattled away; but when they heard it going they guessed why Murdock had dropped it, namely, because the noise was so alarming. I believe that model is in possession of one of the Tangyes now. We have been interested in seeing the "Turbinia" and the "Viper," into which vessels Parsons put his turbine and showed to the country, and to the world, its possibilities, and certainly the enormous speed he got up on the "Turbinia" of 40 miles per hour was an extraordinary fact, and that made engineers realise the capabilities of the turbine. As Mr. Noel has pointed out, the turbine made its principal mark in ocean going steamers, and one can hear from the questions asked that the rolling mill people are interested and are hopeful that something can be done for them in, I suppose, reducing costs. That may come by and bye, but as in the case of marine propulsion, I have no doubt these brief instances will present problems of their own which only ingenuity and perserverance can overcome. I sometimes think when I hear the turbine discussed, of how much the makers of the turbine and makers of other engines, of high efficiency, are indebted to an individual of whom we hear very little, and that individual is the boiler maker. But for the boiler maker increasing the efficiency of his boilers, we could not have the great efficiency we have in the various types of engines so largely used. I mention this fact only as one which has appeared to me a great credit to an industry towards which we are apt to forget our indebtedness. Without detaining you further I beg to move, upon your behalf and my own, our heartiest thanks to Mr. Noel for stepping into the breach in Mr. Izod's illness, and for giving us so much enlightment upon this interesting subject; we shall certainly carry away with us clearer ideas as to its construction and its applications. Gentlemen, I beg to move a hearty vote of thanks.

The resolution of thanks was carried unanimously, and with acclamation, and a suitable response by Mr. Noel brought the proceedings to a close.

The Seventh Meeting of the Session was held at The Institute, Dudley, on Saturday, April 13th, 1907, Mr. William Somers (President) in the chair.

The Minutes of the last Meeting were read, approved, and signed.

On the proposition of Mr. C. E. Edwards, seconded by Mr. Frank East Nurse, Mr. J. Raybould and Mr. W. W. Pagett were elected Auditors of the Institute's accounts for the year ended 31st December last.

Mr. William Jno. Foster then read the following paper:—

THE BLAST FURNACE PRACTICALLY AND THEORETICALLY CONSIDERED.

By W. J. FOSTER.

In this paper, prepared at the request of the Council of the Institute, I shall endeavour to the best of my ability to define the nature of the very interesting processes involved in working a blast furnace.

Although it is generally acknowledged that the process I am about to examine is one that probably involves the most difficult and complicated problems in metallurgy, and this is clearly illustrated by the enormous amount of discussion in various parts of the world which the introduction of the dry air process by Mr. Gayley has occasioned, it is my intention to avoid everything that does not directly affect the problems under examination. I wrote a paper on the Thermal Efficiency of the Blast Furnace for the meeting of the Iron and Steel Institute, held in London in May, 1904, expressly to point out that, although it was generally considered that the hot blast theory, which was based on the lines previously suggested by the late eminent metallurgist, Sir Lowthian Bell, and others, was finally solved, I did not agree with that view, and as briefly as possible attempted to explain my views on the matter, together with other minor practical questions, in the hope that I should particularly raise some discussion on this very important subject—a subject that has engaged the attention of many eminent metallurgists in different parts of the world since the formation of the Iron and Steel Institute in 1869, and also of many others directly associated with the manufacture of pig iron since the introduction of hot blast in the year 1828. Before I attempt to define the principles upon which, in my opinion, the hot blast theory rest, and consequently those of the internal efficiency of the blast furnace, I wish first of all to draw your attention to the measure and method adopted by Sir Lowthian Bell, which is described in the table below, and which represents the heat evolved, and appropriated, in a furnace 70 feet in height, and which was blown with cold air.

... equal ...	34·51 cartes.
...ing off ...	1·86
...	32 65 cwts.
... x 2400 =	78,360
5 x 5600 =	28,000
	106,360

$\frac{106360}{38} = 2799$ calories.

		Calories.	Cwts. of Coke at 2799 Cals.
	·95 x 640=	608	·218
The Seventh Me...	18·60 x 1780=	33,108	11·828
Dudley, on Sa... (President in the	·60 x 2400=	1,440	·515
...	15·50 x 370=	5,735	2·049
The Minutes of	1·86 x 3200=	5,952	2·126
...last, On the propo... ...	·14x34000=	4,760	1·706
East N... Auditors of the I...estimate ..	=	4,200	1·500
last. ...	20·00 x 330=	6,600	2·358
Mr	30·00 x 550=	16,500	5·895
...tion, etc.	=	3,500	1·250
		82,403	29·445
... escaping gases ...		23,957	8·555
		106,360	38·000

... estimated heat evolved is based on the carbon ... burnt at the tuyeres, after deducting an equivalent ... that entering the furnace with the limestone on the ... carbonate of calcium is decomposed below that zone where reduction first takes place, and assuming that ... acid gas takes with it an equivalent of carbon,

Thus:—$CO_2 + C = 2\,CO$.

97 $\quad$ 29 x 2 = 58 calories,

[illegible] THEORETICALLY CONSIDERED

[illegible] change [illegible] a highly [illegible]

[illegible] dealing with a furnace using [illegible] quantity [illegible] equivalent [illegible] quantity [illegible] involving [illegible] consequently [illegible] measure [illegible] calories [illegible]

[illegible]

[illegible] represents [illegible] measure [illegible]

[illegible]

Every other chemical and physical change [illegible] same way, with the result [illegible] where the total calories are equivalent [illegible]

[illegible]

To represent the saving of coke [illegible] introduction of blast heated [illegible] measure [illegible] mentioned [illegible] furnace [illegible] developed [illegible] would establish [illegible] series [illegible] blowing [illegible]

[illegible]

The estimated [illegible]

[illegible]

Consequently the [illegible]

[illegible]

Again, the measure used shows the impractical temperature to which the blast would have to be heated, assuming that one ton of pig iron is produced from Cleveland stone with 15 cwts. of coke. In this case the total calories that would be required from the, when ascertained, supposed best Cleveland practice is reduced from 88,000 to 85,000, due to the, supposed, less fuel used, and also to a reduction in the escaping gases, and may be represented as follows :—

Coke delivered, 15 cwts., less 1·35 ash.

Total carbon = ...	13·65 cwts.
Carbon in limestone as CO, carrying off an equivalent of carbon	1·65 „
Burnt at Tuyeres ..	12·00 „
12 × 2400 burnt to CO = ...	28,800
5·75 × 5600 parts of above burnt to CO_2	32,200
	61,000
Leaving to be provided by hot blast ..	24,000
	85,000

$\therefore$ 24,000 cals. ÷ ·237 SH ÷ 69·6 of air
= 1455° C.

In this particular case it will be seen that the actual saving of coke due to raising the temperature to 1455° C. is slightly less than 5 cwts.

The above measures are, to my mind, altogether out of the question from a practical point of view ; therefore, any theoretical problem worked out on these lines would not be of any great value as a guide to the practical engineer or furnace manager, whose ambition it is to go one better than the present.

As pointed out in my paper * to ascertain the nature of the hot blast, theory, and consequently the general system upon which the process is mathematically founded, we should require a thoroughly accurate knowledge of the Thermo-Chemical conditions of the whole of the matter involved throughout the process. To accomplish this it must be understood that the question we have to solve is the difference of the specific heat of all the matter introduced into the system, from the lowest to the highest temperature existing in the blast furnace ; for it is quite certain that the ultimate results of a chemical change depend entirely upon the quantity of heat absorbed into or passed out of the system. In other words, the equilibrium of a chemical compound is altered in proportion to the heat taken into or expelled from the system, therefore assuming the pressure is known, the result of any chemical change can be ascertained.

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* *Journal I. and S. Institute*, page 249, Vol. 2, 1893.

For an example I refer you to the discussion on my paper, where I referred to the partial decomposition of the water molecule when being passed into the furnace with the heated blast. In this particular instance Professor Lodin, of Paris, drew my attention to the works of Mallard and Le Chatelier, showing that water does not give the least symptom of dissociation at 3000° C, but I am sorry to find that Professor Lodin did not grasp the nature of my remarks. To define my assertion, I contend that when the water molecule has absorbed the amount of heat which was given out on its formation, viz., 34462 calories, an equilibrium is established which is equivalent to complete decomposition; that this decomposition may be brought about without the direct assistance of any other chemical element whatever to take hold of the oxygen or hydrogen, and that a simple catalytic agent, under certain conditions, would completely decompose the molecule into its constituent elements.

The chief point of my argument is, that any heat units necessary for complete dissociation, short of the desired quantity, is a measure in direct proportion towards bringing about dissociation, and therefore any heat absorbed by the molecule is held latent until the whole of the heat required has been supplied. From this I arrived at a practical formula * to ascertain the approximate quantity of heat actually taken into the furnace with the moisture in the air blast, and is therefore necessarily estimated independently of the nitrogen and the oxygen, so that we could arrive at the quantity of heat actually absorbed in the hearth of the furnace due to what I referred to as partial decomposition, derived from the superheating of the air on the one hand, as a comparison when heated at different stages or degrees, from the average temperature of the atmosphere on the other. To more clearly emphasise what I wish to explain, it might be interesting to ascertain the exact theoretical temperature necessary to establish an equilibrium, that would be equivalent to the complete decomposition of the molecule, without the aid of any agent other than heat. This may be represented by the following formula, which is simply a question of dividing the calorific power resulting from the combination of the two elements, hydrogen and oxygen, by the weights of the products of combustion multiplied by their respective specific heats, thus:—

$$‡ \quad 34462 - \left\{ \frac{[(1-0{\cdot}4805)\ 100] + 537}{9 \times 0{\cdot}4805} \right\} 9 = 6743{\cdot}5^\circ \text{ C.}$$

which indicates that we require 6743·5°C for complete decomposition. From this fact one can naturally understand the enormous temperature to which we should have to heat our air blast, to get a comparatively small amount of benefit in the absence of an intermediate agent. I particularly draw your attention to this train of reasoning, chiefly for the purpose of attempting to expel from the minds of some of the Continental critics on Mr. Gayley's paper on Dry Air Blast, who contend that an equivalent of

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* *Journal I. and S. Institute, Vol.* 1, 1904.

‡ Assuming the specific heat of gaseous H_2O is constant at all temperatures.

heat to the air blast is directly equal to abstracting an equivalent of moisture from the air. It might also be interesting to point out a few practical questions that these theoretical metallurgists appear to have overlooked. For example, I think it is well understood in blast furnace practice, that by temporarily increasing the blast to an abnormally high temperature, we at once have a corresponding increase of internal, and also to a less extent external, resistance to the blast and gases, which of course at once suggests that we require a corresponding increase of energy to overcome this resistance so as to force the gases through the furnace. It is also well understood that furnaces working with super-heated air, require a corresponding increase in the tuyere area, due to the increase in volume of the air, which means that in construction we have to provide for more tuyeres or make the same quantity of tuyeres proportionately larger. In the first case complications are introduced, while in the latter the life of the tuyere is reduced considerably, which is independent of a reduction in life due to the increased temperature only, so that conjointly these items have to be seriously considered; also the extra cost in stove repairs due to overheating, etc., is a question that must not be overlooked. Further on in the paper I shall endeavour to show how physically impossible it is to economise after a certain temperature has been reached, which conditions will be found to vary according to circumstances.

* Tabulated below is the method I have adopted to illustrate the appropriation of heat, etc., to the various parts of the system, which was estimated in January, 1904, when the cost of coke per ton of iron equalled 23·36 shillings.

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* For simplicity the unit of heat employed is equivalent to one ton of carbon=8080 calories.

	Calories.	*Coke in cwts.*	*Cost in Shillings.*
Reduction of iron oxides ...	1391·000	3·912	3·130
Reduction of silica	254·470	0·716	0·573
Reduction of phosphorus ...	85·630	0·241	0·193
Reduction of oxides of sulphur ...	0·660	0·002	0·002
Reduction of oxides of manganese	18·090	0·051	0·041
Reduction of calcium in slag, estimated as sulphide ...	38·437	0·108	0·078
Expulsion of CO_2 from limestone	236·910	0·665	0·534
Fusion of pig iron	330·000	0·928	0·743
Decomposition of water vapour in blast	172·580	0·478	0·390
Heat carried off by gases, including H_2O in coke, etc. ...	769·446	2·164	1·732
Fusion of slag	548·310	1·542	1·235
Heat carried off by tuyere water ..	50·992	0·144	0·117
Heat carried off by cooler water...	31·875	0·089	0·071
Carbon taken up by pig iron ...	282·800	0·796	0·637
Loss due to radiation, absorption in foundations	727·164	2·052	1·685
Combustible matter in gases ...	5444·440	15·312	12·248
Total heat, coke, and cost from 1·285 tons carbon ...	10382·800	29·200	23·680
Heat brought back with hot blast	695·340	1·954	1·650

In capacity the furnace under examination, perhaps with the exception that it is a little larger, is very similar to the one previously mentioned, and is also worked with hot, and occasionally cold blast, and for this reason I have selected the cold blast furnace examined by Sir Lowthian Bell for the purpose of comparing the two different measures, namely, the one adopted to arrive at the results demonstrated in the previous table, and the other, the one that I shall attempt to define, the results of which are shown in the present table. A casual glance at the results just described in the above table will, I think, at once convince you of the vast difference in the proportioning of the heat and fuel necessary to fulfil the functions of the various parts of the system. For example, you will see the enormous difference representing the reduction of iron, a definite quantity in both cases attributed to be necessary to produce one ton of pig iron. It will be seen that in the case cited by Sir Lowthian Bell he gives 11·828 cwts. of coke as the quantity necessary for reduction out of a total of 38 cwts., while on the other hand I can only account for 3·912 cwts. out of a total of 29·2 cwts. of coke (as I previously pointed out to the members of the Iron and Steel Institute in May, 1904) I attribute for the reduction of iron oxide per ton of iron made, and similarly for the reduction of phosphorus, silicon, sulphur, manganese, and carbon taken up by the iron. Likewise the fusion of the pig iron itself requires a constant quantity of heat, or calories, and consequently coke, which corresponds in this particular case to 6·646 cwts. only, so that no matter what the conditions of working, whether in the coke furnace or any other furnace, we must attribute a definite weight of fuel to these parts of the system (assuming that the iron produced has the same composition); therefore, we cannot look for any further fuel economy in this respect under any conditions whatever. On the other hand, all the other figures representing the remaining parts of the process are subject to alteration according to the mode of manufacture, together with a careful study of the properties of the materials to be used, and following this train of reasoning I attempt to define a measure which I consider will, when applied with scientific and practical skill, be of great value to the blast furnace manager. This, I consider, should be based on the highest absolute efficiency for the reduction of pure * iron oxide by means of pure carbon, although for certain obvious reasons it will never be found practical in a blast furnace, but I am of opinion that it should be every blast furnace manager's ambition to attempt to reach this goal of fuel economy.

It will be seen in Column 2 that the actual equivalent of coke necessary to reduce the iron oxides entering the furnace is only 3·912 cwts., and that when we add to the 29·2 cwts of coke actually used the equivalent of coke introduced by the hot blast, viz, 1·954cwts., we get an excess of (29·2 + 1·954) — 3·912 = 27·242, and again after allowing for the reduction of all the oxides, and the fusion of the iron, we still get a loss of (29·2 + 1·954) — 6·646 = 24·508cwts. of coke.

In my previous paper † the loss due to radiation was estimated, by difference, to be equal to 2·052cwts. of coke, but unfortunately an error has crept in, due to omitting the value of the heat introduced in the blast and the loss, found by direct experiment, due to the heat carried off by the water used for cooling eight 5in. tuyeres, one slag tuyere, and eight coolers, which necessarily makes the actual loss equivalent to 2·052 + 1·954 + ·233 = 4·239 cwts., thus showing a greater efficiency in case of rapid driving than was actually accounted for.

The very peculiar fact which appeals to us in blast furnace practice, is that we find ourselves compelled by our present method of manufacture to inject oxygen into the furnace at the tuyeres for combustion. Now oxygen is practically the sole element that we wish to eliminate from the oxides, and is found in combination with the materials from which pig iron is produced, and the most striking fact is, the more oxygen there is introduced into the furnace in a given time with the air blast (assuming the plant generally is properly proportioned), so do we require proportionally less oxygen injected per ton of iron made; therefore,

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* Fe_3O_4 is adopted on account of our knowledge of its accurate calorific value.

† *Journal Iron and Steel Institute*, May, 1904.

from these few remarks, it appears to me that * rapid driving, with a plant equipped to meet the necessary circumstances, is a direct path to fuel economy. To obviate the repetition of the numerous thermo-chemical problems, I have endeavoured to construct the accompanying diagram—which is based upon my own observations—in such a way that the whole question is concentrated and simplified, and a clear definition of my views can at once be grasped by any practical man.

It will be seen by the line in the diagram representing the tons of air required that the quantity of air necessary to be injected into the hearth of the furnace practically varies in direct proportion to the carbon used, and from my own experience I think that the absolute zero which would decide the requisite quantity of either carbon or air, would appear when the oxygen introduced with the oxide of iron is chemically equivalent to the pure carbon necessary for its complete oxidation, according to the following equation :—

$$Fe_3O_4 + C_2 = Fe_3 + 2CO_2$$

$$265{\cdot}8 \qquad\qquad 97 \times 2 = 194.$$

and although this equation proves that the reaction is endothermic (thus 265·8 — 194 = 71·8 calories) still this seems to me to be the point when no external air or oxygen would be required for internal purposes. Assuming that the deficiency of 71·8 calories is introduced into the system by some other method or agent than the blast, to balance the heat required, as shown in the equation, I consider that the necessary carbon required to reduce one ton of pure iron from the oxide as represented above should be taken as zero for the external oxygen supply. In this case 2·857 cwts of carbon is required, and although the total carbon required to put the above equation in a state of thermo-chemical equilibrium would be (194 : 2·857 : : 71·8 : 1·057 .·. 2·857 + 1·057) 3·914 cwts, still the point defined as the zero or minimum of external oxygen or air supply, which in this case is calculated from the absolute ideally efficient reduction of pure iron oxide, and is represented in the diagram by † 2·857 cwts. of carbon is the starting point from which I not only attempt to explain the hot blast theory, but every other chemical or physical change that may be introduced into the system, either directly or indirectly; and assuming that the thermo-chemical nature of the unit introduced is previously thoroughly understood, I consider this measure is of great practical commercial value.

Undoubtedly the most important question andone that has during the past two years caused a vast amount of discussion, is that dealt with in the paper read before the Iron and Steel Institute in America by Mr. Gayley on the application of dry air blast; it has undoubtedly put all the theoretical

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* See Discussion *Journal Iron and Steel Institute*, May, 1904.

† Owing to a small quantity of iron free from oxygen being added to the charge at Darlaston in 1904, the carbon zero was estimated at 2·438.

experts practically in a state of confusion, for it is evident that a theoretical explanation of the dry air question is quite as complicated as that of the hot blast theory, and to my mind can only be explained in a similar manner, seeing that it affects the thermal conditions at the hearth by absorption of heat, † due to the decomposition of the water vapour, just as a reduction of the blast temperature would, assuming the thermal conditions in both cases were equivalent.

In the diagram it will be seen that I have endeavoured to explain the nature of the dry air problem by means of the lines extending at an angle upwards from what I call the ideal efficiency point, which is shown by the horizontal line, where 2·438 cwts. of pure carbon is indicated. It will be observed that at this point no air is required and consequently no moisture, but it will be seen also that at the horizontal line representing the conditions which I proved to exist, at Darlaston, in the year 1904, that the actual air injected into the furnace was 6·377 tons per ton of pig iron, and the actual average quantity of moisture present in the blast, also proved by direct thermal calculations, was equivalent to a saving of only 0·47 cwts. of coke. On the other hand, it is shown by the second line from the left that I attribute a saving of 2·786 cwts., which is the quantity of fuel I should expect to save under these conditions of working, assuming that the whole of the water vapour had previously been eliminated from the injected air blast. I have on a previous occasion, when discussing Mr. Gayley's paper, pointed out that a cold blast furnace would naturally benefit more by the use of dry air than would be the case with a furnace using hot blast, but even in this case the ratio of saving would be directly affected according to the line extending at an angle from the point where 36·96 cwts. of pure carbon, or 42 cwts. of coke, is required per ton of iron. By following the first line from the left it will be seen that the actual coke saved at Darlaston, due to heating the blast to 454·5°C, was by direct calculation (based simply on the amount of heat absorbed in raising the temperature of 6·377 tons of air through 454·5°C, which injected into the furnace 695 calories) 1·954 cwts.; but on the other hand it will be observed by a glance at the third straight line from the left, downwards, that by heating the blast to the same temperature 12·8 cwts. of coke per ton of iron is actually saved, which is approximately what was represented in the dry air question, *i.e.*, about a saving of six times as much as is accounted for by direct thermal calculations.

The most important question for a blast furnace manager when working under different circumstances, either of plant or materials, is how to attain the most economical conditions—internal and external—by heating the blast to the desired temperature. For example, it will be seen from the diagram that when rich materials are reduced with a well-designed plant, heating the blast to an exceedingly high temperature is not so advantageous as when we have to deal with inferior materials in a badly equipped plant. Take the Darlaston conditions for example; it will be seen that the saving of coke due to heating the blast through 454·5°C is represented, as mentioned above, by 12·8 cwts.; but on the other hand suppose we double the temperature of the blast, and raise it to 909°C, it will be observed that the air required will be reduced to about 4·8 tons, which corresponds to an additional 345 calories injected, and a further saving of about 6·7 cwts, of coke. Therefore although we can only account for a saving of fuel of approximately one-half of that which was obtained by the first increase of 454·5°C, still it clearly proves that when we raise the average temperature at Darlaston to 909°C, the actual fuel required per ton of iron would be 22·5 cwts. instead of 29·2—or a reduction from the cold blast line of 19·5 cwts.

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† See *Journal of the Iron and Steel Institute*, Vol. I., 1902, pp. 296, 303—The unit of heat employed when describing the thermal nature of a chemical change is equivalent to raising a kilogram of water by the complete combustion of one gramme of amorphous carbon through 1°C.

[*] Again, suppose it was physically possible to heat the blast another 454·5°C, and the ultimate temperature was brought up to 1363°C; the additional temperature in this case would only be equal to 3·75 cwts., making up a total of 23·25 cwts. from the cold blast line, and the air required would correspond to 3·85 tons, equal to a temperature corresponding in the curve sufficient to inject 1260 calories.

From the foregoing remarks when dealing with the question of using dry air instead of the normal atmosphere, it will be seen that according to the diagram, a furnace requiring 15 cwts. of carbon, or 17 cwts of coke, would in this country have an approximate average moisture of 69lbs. in the 3·4 tons of air used, and assuming that the whole of the moisture was eliminated, I can only account for a saving of 1·5 cwts. of coke. On the other hand Mr. Gayley shows a saving of 435lbs of coke, or nearly 4cwts. per ton of iron, when only eliminating an average of 0·7 grain of water per cubic foot of air, which is only practically equivalent to 13·5lbs. of water eliminated per ton of iron. Assuming that the ratio of coke saved is worked out in proportion to the actual water removed from the air. it will be observed that while I can only account for 1·5cwts. of coke per 69lbs. of water, this quantity, according to Mr. Gayley's calculations, is equal to 13·5 : 435 : : 69 : 2,223lbs., or nearly 20cwts., astounding figures, for it is quite evident that no scientific explanation has yet been advanced that could account for such a saving. It must be borne in mind that the saving I referred to, viz , 1·5cwts., is based on absolute normal conditions, and assumes that the working of the furnace is in no way interrupted by those irregularities which are quite common in the best regulated practice.

Some twelve years ago, as a furnace keeper at the Barrow Hematite

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[*] Formula adopted to decide temperature curve $= \frac{\text{cals}}{\text{air x SH}} = \frac{1260}{3{\cdot}85 \times {\cdot}24} = 1363°\text{C}.$

in reality the SH would be higher as the temperature increases.

Steel Co.'s works, I had a considerable amount of experience, especially with their No. 9 furnace. The furnace was supposed to be built on modern lines, and although Mr. Thos. Danks—the present furnace manager—did not build it, I have no doubt that it was to his deep regret that he had the responsibility of working it. As far as I can remember, for the first twelve months from blowing in, the furnace had very nearly all her own way; in fact, to my sorrow she would cast when she liked, where she liked, and very often too. Eventually the cause of this condition of things was ascertained, and although it was suggested that she was channelling, still it could not be found out by the trying rod at the top or filling hopper in the usual way, so that it had to be detected at the tuyeres, which required very careful examination. I have on numerous occasions noticed that when we have ascertained the particular tuyere, or tuyeres, which directly fed the channel, or path of least resistance, we have actually changed the colour of the slag in from thirty minutes upwards, according to the general conditions of the furnace, from a jet black to a white limy slag.

I only mention this as an illustration of the great change suddenly brought about by simply interrupting irregular working conditions. In such a case as that given above it spelt economy in fuel when properly applied. In my opinion the application of dry air to a furnace working under the unfavourable conditions above stated would be of greater advantage than when applied to a furnace working under normal conditions.

Now that I have attempted to define my views of the principle upon which the working of the blast furnace rests, and which is, as far as I am concerned at present, clearly illustrated by the diagram, I do not think it advisable at the present stage to proceed to explain the whole question in detail. To do so would involve the explanation of numerous physical and chemical changes, and would introduce unnecessary complications; but, on the other hand, I reserve this information for discussion at some future date, and trust that any points, either practical or theoretical, which may arise will be stated as definitely as possible, no doubt to our mutual advantage.

In concluding, I sincerely trust that my views on the blast furnace have been defined to all who are interested in it directly or indirectly. We have plenty of room for improvement, even in the most up-to-date practice, particularly so in the Black Country district of England, and although a few of our leading firms have attempted to Americanise their plants, some of them, perhaps, with little or no apparent direct economy on the old practice, still that is no criterion why the British Empire should be content to be deposed from the first to the third place in such a comparatively short period. I am afraid that the reason for this is beyond a scientific explanation, but the matter should be carefully studied. On coming to the Black Country some nine years ago, I had the pleasure of discussing the general condition of the district with my esteemed friend

Mr. Donechay, who, when commenting on the blast furnace, gave it as his opinion that blast furnaces are very much alike all the world over. Yes, I thought so, was my reply. I feel confident that what that most eminent blast furnace manager, Mr. Gayley, has done in America with his fast driving, should at least have been, without the introduction of complications, an incentive to better furnace practice in this country, and the future, to my mind, will see great strides in this direction.

During the last few years, particularly in America, the question of internal explosions has attracted the attention of numerous experts in the manufacture of pig iron owing to the serious accidents which have occurred from time to time, due, it is usually considered, to an explosive mixture accumulating in the lower part of the furnace. In discussing Mr. Sahlin's paper on the Julian Kennedy furnace filling, read before the Iron and Steel Institute in May, 1903, I endeavoured to explain the nature of the various kinds of explosions, and I am pleased to see, from a paper recently read by Mr. Julian Kennedy in America, that he attributes great importance to my suggestions, particulary to what, in my opinion, was simply a question of displacement of accumulated gases at a high pressure from the hearth to the upper part of the furnace. It is well understood in practice that when a furnace has been scaffolding very badly for a considerable time it usually melts itself hollow in the hearth and bosh. This can readily be ascertained by the ease with which a rod can be pushed through the tuyeres into the centre of the hearth, and not only can this be done but it is often actually possible to approximately measure the capacity of the compressed gases in the hearth and bosh, and consequently arrive at the nature of the scaffold.

Under normal conditions the pressure at the top of the furnace varies from that of the atmosphere upwards according to the general conditions of resistance in gas mains and in the furnace itself and also the initial pressure at the hearth near the tuyeres. As I have previously stated I have ascertained that the greatest resistance to the gases in the furnace is chiefly in the zone of fusion; this point of course varies in the hearth and bosh according to the various continually changing conditions of temperature. It is quite obvious that in the case of serious scaffolding, the materials which previously offered the most resistance to the travel of the gases have been partly melted away and that when they are suddenly melted through or released by the contraction of the previously semi-fused materials, the slip allows the highly-compressed gases followed up immediately by the gases generated by the compressed blast, to pass into a zone of the furnace offering considerably less resistance, with the result that owing to the increased velocity of the ascending gases the materials are projected into the downcomer, or if the furnace top is not made sufficiently strong to meet the circumstances then it is possible that the whole charging apparatus would suffer disaster.

THE DISCUSSION.

Mr G. H. Gibbs: Mr. Foster's paper leads one to suppose tl consumption of carbon, due to the reduction of iron from its oxi a very variable one, and as instances, quotes the consumption Lowthian Bell's cold blast furnace as equal to 11·828cwts. (ot and in the same furnace, with blast heated to 485°C., the consui of coke for the same purpose is estimated at 9·207cwts., and ag Darlaston the estimate for the same work is 3·912cwts. only. contention is that as the reduction of iron from its oxides is perf by the chemical action of the carbonic oxide in the ascending the amount of carbon so used to reduce 20cwts. of iron is prac the same in all cases, and the theoretical minimum of carb required will be (if the oxide exists wholly as Fe_2O_3) nearly 5 yet this result, which could hardly be attained under experi conditions in the laboratory, is higher than Mr. Foster's fig Darlaston—viz, 3·912cwts.—by about 1cwt. of coke to the ton (Seeing that in practice this theoretical minimum for reduction (be attained, since it is impossible to work with an ascending c of carbonic oxide equal in volume to that theoretically requi reduce the descending column of iron oxide, as the CO and Fe_2 not sufficiently intimately mixed (just as it is not possible to b quantity of coke in an ordinary grate with the theoretical amo air required), then the factors of economy in reducing the oxide \ found in the amount of carbon carried off as CO in the furnace examination, together with the amount of sensible heat carried by the waste gases of the furnace, which will vary greatly, approximately one-third more in the cold blast than in the hot furnace. On page 115 of the paper under discussion, in maki his estimate, Mr. Foster has neglected the fact that the whole blast in the cold blast furnace has to be heated up in the fı itself, and also that the weight of the blast is one-third more than hot blast furnace, and therefore one-third more CO is carried a\ the top of the furnace, in addition to one-third more sensible h the gases, so that it does not appear that the figures quoted in the are of much real help in comparing the two cases, *i.e.*, the colc furnace, and the same furnace using hot blast. The amount (over and above that theoretically required for reduction of iron should be practically the same in any furnace under examinat the quality and nature of ores and general working conditions a same. In the remarks on the Darlaston furnace, it is stated to b similar to Sir Lowthian Bell's furnace using hot blast. As th will be presumably Cleveland in the one case and Northampton other, and of something like the same metallic contents (probal to 36 per cent. Fe), how can such a wide difference for this on $Fe_2\ O_3$) be justified as the 9·207cwts. in the one case and 2cwts. in the other. Referring to the bottom of page 122 of the er, another factor, in addition to the temperature of blast, which ences the economical production of pig iron, is the rate of driving, this will be more apparent in large furnaces than in the smaller found in this district. The basis points to consider in this ection are the amount of iron and slag to be melted within a given in a given time. This will govern the weight of air to be driven the furnace in a given time, and consequently determine the perature of the hearth, which will be much above the actual melting t of the slag, and as the slag and iron have to be fused very dly, thus absorbing the heat evolved at the tuyeres more quickly, heat intensity is naturally greater than in a furnace being driven er more moderate conditions. Radiation losses are less per unit ght of pig, and the iron and slag do not have to stand in the rth so long absorbing heat. Two typical instances are here given llustrate the economy due to the intensity of temperature. First, ting a bottom on an open hearth steel melting furnace, at a perature of about 1,700°C. It would be possible to burn gas in the nace for weeks without any satisfactory result at a temperature of 0°C. less than that required, whereas by raising the temperature to e extent of only 100°C. as many days would suffice, with a correonding saving in the amount of heat employed. Secondly, as an treme case, if one were to attempt to freeze a sheet of water 6in. ick, at a temperature of 32°Fahr., it would be a long job, but by wering the freezing point 5 or 6°, the ice is soon obtained, and with a uch less direct expenditure of cooling effect.

Mr. WALTER JONES: Personally, I must congratulate Mr. Foster pon having written a very excellent paper, especially since he has welt so largely on the practical side in addition to the theoretical. I notice he adopts the calorie as the unit of heat measurement; I presume it is more convenient than the British thermal unit. Some of my friends think I have a grudge against the British thermal unit, a very interesting fellow, but as elusive as De Wet. I am glad to see that Mr. Foster enlarges on the practical side throughout the whole of the paper. On page 116, he says: "The above measures are, to my mind, altogether out of the question from a practical point of view; therefore any theoretical problem worked out on these lines would not be of any great value as a guide to the practical engineer or furnace manager, whose ambition it is to go one better than the present." I would just like to say a word or two upon that subject as regards working at lower temperatures with water and steam. I have come across some instances where the differences have been enormous, considering the low temperatures worked at. When you want to get 100 degrees of inside heat I don't know of any formula which can be used with correctness. I think you will remember that I raised this question when Mr. Wall read a paper not long ago. Most people consider these units to be the same at most temperatures, and that is why we all get astray. If you take a penny as a unit and multiply by twelve you get 1s., and it comes right every time, but when you are dealing with questions of heat and heat losses, you find that as your temperatures increase, the volume of air increases, and your losses increase at a most alarming rate. There is a very wide variation. On referring to Mr. Thomas Vaux's book on "Heat," p. 205, I find he says that the ratio of loss varies from ·94 to ·72, according to the difference in temperature, *i.e.*, by increasing the temperature to 116 degrees only, the ratio of loss is 82 per cent. greater. As to Table 106 he says that as a heated body increases from 490 degrees in contact with air at 60 degrees, the ratio of loss is 3·1 per cent.; but if you increase it to 1,500 degrees instead of 490, the ratio goes up from 3 to 80 per cent., and if you increase it to 3,580 degrees in contact with air at 60 degrees, the ratio of loss is 4,604, *i.e.*, the ratio of loss at red heat is 2,200 per cent. and the ratio at white heat is 148,000 per cent. difference. Therefore you must not take these heat units as being constant at all temperatures. I have had many instances of this during the last few years, and have spent considerable time in trying to arrive at definite figures with regard to lower temperatures, and I congratulate Mr. Foster upon dealing with his matter of high temperatures in the able way he has done. I could give you one or two curious illustrations of losses of heat units. A man once wrote me saying that if he could get a radiator holding 12 gallons it would keep a good sized room warm, but I had to reply that it would require ten times as much heat as he said. He had forgotten the heating of the walls, the ceiling, &c. I lent him a radiator and have not heard from him since. One of my staff calculated in a certain case that there would be required 800,000 heat units, but on making my own calculations I made it out to be 16 millions. You have to take great care of this matter of heat losses. I can quite imagine that to blast furnace managers this paper will be of extreme interest.

Mr. R. Buchanan: I have not the good luck to be a blast furnace manager, though I have the misfortune to use their products sometimes; but I think this paper ought to be to the blast furnace man of a most suggestive character. I must admit it is not easy reading. Mr. Foster, in tackling Sir Lowthian Bell's data as regards blast furnace practice, shows very considerable courage, and a courage, I think, which could only come from a young man. We are apt to accept old hoary-headed traditions of science as irrefragible and beyond doubt, and it is a very good thing that some of those old accepted pleas should be investigated to see whether they are perfectly true or not. Sir Lowthian Bell's figures may be perfectly correct, but there can be no harm in anyone verifying them. As an instance of errors which creep in, we may take Fairbairn's results of the repeated meltings of cast-iron which are given as standard results. On analysing a sample of iron which had been kept over from those experiments, it was found that the analysis of Fairbairn's time was totally wrong. With the newer instruments, greater knowledge, and greater care, it was found that Fairbairn's analysis was wrong and that, consequently, the deductions drawn from them were also wrong. That is another instance of the need for finding out whether old ideas are incorrect or not. It is right for Mr. Foster to try his best to get at the truth, and let those who think him wrong prove him wrong. Mr. Foster does not claim, I take it, to solve the whole question of the influence of hot blast. That influence is sometimes extraordinary, You appear to get such tremendous results from comparatively small degrees of heat applied through the blast. Now I have been puzzling my mind—as many a better man has done—as to the reason why such extraordinary results are got from a small addition of heat. Roberts-Austen shows that the addition of heat to the blast causes the carbon to give you a greater amount of heat than when the blast is cold. This phrase of "depulverising" seems to me to be a phrase for gathering up certain results of which we do not know the cause, and one does not wonder that there should be such attempts to explain what I think we all admit must be unexplainable. But neither does Mr. Foster explain how these results come about, and so there arises the necessity of still further investigation, which I have no doubt would require to be of the most patient and thorough character, for the views of Sir Roberts-Austen form only a very partial endeavour to explain it. Mr. Foster's remarks about explosions in blast furnaces are no doubt very interesting, and I have observed that Mr. Julian Kennedy has been paying some attention to the subject, and so far as I can see he largely copies the views which Mr Foster has expressed as to the conditions under which those explosions take place, but fails to give his authority. In conclusion, I must tender my thanks to Mr. Foster for so interesting a paper, and express my hope that he will still further extend his investigations and submit them to this Institute.

Mr. H. Siviter: There is one point I should like to mention. When a furnace is driving very fast for a few weeks, does it not occur to practical men that for two or three days afterwards it works irregularly? I have noticed this and should be glad to hear if anyone else has noticed the same thing, and should also like to know the explanation.

Mr. Foster: If you will refer to my paper read before the Iron and Steel Institute in 1902 you will get information about that.

Mr. W. Kendrick: As a user of pig iron, I should like to ask Mr. Foster whether the quality of pig iron has deteriorated since greater heat has been employed in the melting? We are told that cold blast iron is worth more than hot blast. Now if cold blast makes the best iron, to what point do we go in hot blast until the iron becomes inferior? Do we go down the scale of quality as we raise the heat, and if so, at what point do we begin to go down?

The PRESIDENT: I rise for the purpose, not so much of discussing the subject, but of proposing a vote of thanks to Mr. Foster for his paper. He says that "Although a few of our leading firms have attempted to Americanise their plants, some of them with little or no apparent direct economy on the old practice, still that is no criterion why the British Empire should be content to be deposed from the first to the third place in such a comparatively short period." I think Mr. Foster is under a misapprehension here, because we in South Staffordshire are not content to be dispossessed by foreigners. I believe our chief difficulty is that we have no proper waterway from the Midlands to the coast, but we can, at any rate, see that the fullest and freest discussion given upon such papers as this will help to introduce new ideas into practice and be correspondingly beneficial. Many American machines which are sent over to England are condemned in engineering lectures because they are rather cheap, and especially because they are intended to be pushed along for all they are worth during a short time, and then to be put on the scrap heap to make place for something newer. Americans believe that a piece of machinery is only good for two or three years, and then you ought to have made sufficient money from it to put it on the scrap heap. English people, on the contrary, make a machine to last for about ten years or more, and then build it up again and again. I believe in the American ideas to a certain extent, but not altogether, and I am perfectly certain that if England will only make its machinery last not quite so long as at present, and if managers will only remember that if machines are really obsolete they ought to be thrown out, then we have not much to fear. Some of the members saw a large new German press at our works recently, but would have seen an English one instead if English engineers could have made one as good. It is working there now, and I have not the slightest doubt that in a very few years English firms will be able to make as good a press. I have much pleasure in proposing a vote of thanks to Mr. Foster for his paper.

Mr. D. EVANS: I have pleasure in seconding this resolution of thanks for Mr. Foster's very thoughtful and suggestive paper. He referred to a furnace which was very erratic in its behaviour, sometimes working well and sometimes badly, and also channelling. I am not so much concerned about the amount of heat put into blast furnaces, as about what is turned out of them, and what is the behaviour of the iron in our forge or foundry. Of course, the idea of reducing the heat losses is intensely practical. I have come in contact with people before now when I have been looking out for a very nice open cinder pig.

They say, "Why are you always looking after this sort of pig?" and my reply is, "Well, you know, I like to think your furnace is working comfortably and not channeling."

The resolution of thanks was carried unanimously.

Mr. **Foster**: I thank those gentlemen who have taken part in the discussion, and also the members generally for the very kind way in which they have received the paper; but I regret the technical discussion has not left me much to answer. Mr. Gibbs does not seem to have grasped the true principles of the diagram illustrated in the paper. First, he draws attention to the variation of fuel attributed to the reduction of iron oxides, and supposes this to be due to my method of calculation. If he had read the paper more carefully he would have noticed that I base my calculations on a definite measure, which is always constant, and that I compare this factor with the variable quantity which is illustrated by Sir Lowthian Bell's method of calculation. Mr. Gibbs points out that the theoretical minimum for the reduction of sufficient iron oxide (Fe_2O_3) to produce twenty cwts. of pure iron should be based on the assumption that the whole of the iron is reduced with carbon mon-oxide. Therefore, I take it that he considers this a definite measure, which might be represented by the following simple formula:—$3\ CO + Fe_2O_3 = Fe_2 + 3\ CO_2$. This shows that the carbon required for complete reduction is equivalent to 4·642 cwts., instead of nearly 5 cwts. mentioned by him. Further, the quantity of heat necessary to form an equilibrium in this chemical change, a factor which is absolutely necessary, is neglected. Again, he appears to have overlooked the fact that a great quantity of oxides are reduced in the blast furnace by means of solid carbon. The efficiency of the blast furnace is not only dependent on the quantity of carbon mon-oxide and the sensible heat of the gases leaving the furnace, but also depends on the chemical composition of the whole of the gases leaving the furnace, and particularly the ratio of CO_2 to CO. With the greater proportion of CO_2 the efficiency will be increased, and less fuel required. It is quite obvious that Mr. Gibbs has also not sufficiently studied Sir Lowthian Bell's work dealing with questions on the hot blast theory, seeing that he presumes that I have neglected to take into consideration the fact that the air blast when introducing cold, has to be heated to the temperature of the furnace. Who would suppose it otherwise? It is difficult for me to see how he arrives at his conclusions. The air required per ton of iron by the furnace at Darlaston when working on similar materials and under the same conditions generally, was found by actual practice to be 6·377 tons when working with hot blast, and 9·1 tons when working with cold blast. The weights of gases actually leaving the furnace was found to be 8·289 and about 12·1 tons respectively. These are plainly shown in the diagram, and are facts which correspond with my own theoretical conclusions. The chemical changes in the blast furnace are totally different to those produced in the open hearth steel furnace and any conclusions drawn are apt to be misleading. I thank Mr. Jones for his kind remarks and sympathise with him in the difficulties he has experienced when dealing with heat calculations. Mr. Buchanan refers to the phenomena mentioned in my paper, that we actually get a greater saving of fuel by heating the air blast than is accounted for by direct calculations. At Darlaston, I find that we save about six times the quantity of coke that is actually injected into the furnace in the form of heat with the blast. The reason for this will be seen from my general remarks when referring to the diagram. Mr. Siviter is anxious to know why a furnace should work irregularly after a short period of fast driving. This often happens, and is due to irregular filling at the time the furnace begins to exceed its normal rate. The fillers cannot keep up the pace and the furnace is blown with the materials at a lower level from the filling hopper than usual, with the result that the gases leave the furnace at a higher temperature, and, with certain materials, the percentage of carbon dioxide is reduced. Again, it might happen that the furnace and plant in general is not designed to satisfactorily meet abnormal circumstances; but such conditions are very rare, in fact, I can only remember coming across one furnace in this country where the rate of driving was reduced with advantage, and that was done for purposes of safety. With reference to Mr. Kendrick's remarks, the quality of pig iron will be improved by increased driving, even cold blast iron, and particularly iron required for the basic steel process, because we then have less silicon and sulphur per ton of iron made, as less fuel is required to make a ton of iron. Mr. Evans' preference for an open-centred pig is a good one—we rarely get a bad analysis with an open-centred fracture, especially when the honeycomb surface is regular and the manganese in the right proportion.

ANNUAL MEETING.

The Annual Meeting was held on April 27th, 1907, at the Station Hotel, Dudley, the retiring President (Mr. William Somers) in the chair.

The Minutes of the last Meeting were read, approved, and signed.

The Secretary read the following Report of the Council for the session:—

REPORT OF COUNCIL FOR SESSION 1906—1907.

The Annual Excursion took place on the 18th July, 1906, when a party of from seventy to eighty members visited the London and North Western Railway Company's Works at Crewe. On arriving at Crewe the party was met by Mr. Homfray (representing Mr. Whale), and was taken on two of the works loco cabs to the general offices, and then to the Rolling Mill Department, from which a tour of the whole of the works was made under the guidance of Mr. Homfray and other members of the Company's staff. Luncheon and tea were served at the Crewe Arms Hotel, and the President conveyed the thanks of the members to the Company's representatives for their courtesy during the day.

On the 10th inst. a party of about ninety members visited Messrs. Walter Somers and Co.'s Haywood Forge, Halesowen, to witness the large forging press and heavy machinery in operation. The members were shown over the works, and afterwards entertained to tea. The Vice-President (Mr. R. Buchanan) presided, and a hearty vote of thanks was given to Messrs. Somers.

Seven ordinary meetings have been held during the year, at which the following papers have been read:—

27th October, 1906.—Address by President.

17th October, 1906.—Paper by Mr. A. H. Hiorns on "The Combined Influence of Certain Elements on Cast-iron."

15th December, 1906.—Paper by Mr. C. H. Wall on "The Use of Gas for Heating and Re-heating Purposes."

16th February, 1907.—Paper by Professor F. W. Burstall on "Internal Combustion Engines."

16th March, 1907.—Paper by Dr. Alexr. Findlay on "Some Principles of Physical Chemistry and their Application in Metallurgy."

23rd March, 1907.—Lecture by Mr. Noel on "Some Applications of the Steam Turbine."

13th April, 1907.—Paper by Mr. W. J. Foster on "The Blast Furnace Practically and Theoretically Considered."

Membership.—During the year 2 honorary and 23 ordinary members have joined, 4 honorary and 16 ordinary members have left, and 4 members have died, viz.:—Messrs. Ernest Farnworth, Emanuel Harper, Henry Parry, and H. B. Whitehouse. The present number of members is as follows:—

Honorary	47
Ordinary	241
	288
Total number in April, 1906 ...	286
Increase during the year	2

Finance.—From the accounts to be presented it will be seen that the balance in hand on the 31st December last was £156 19s. 4d.

For the Council (*signed*)

WILLIAM SOMERS, President.
WILLIAM H. CARDER, Secretary.

The Treasurer read the audited Balance Sheet for the year ended 31st December, 1906. (The Balance Sheet will be found at p. 141).

On the proposition of the President, seconded by Mr. John Keeling, it was resolved that the Report and Balance Sheet as read be received and passed, and printed in the *Proceedings* for the Session.

The PRESIDENT proposed the election of Mr. Robert Buchanan as President for the ensuing year. He remarked that he was confident that the name of Mr. Buchanan would be received with unanimous approval.

Mr. WALTER JONES seconded the nomination. In electing Mr. Buchanan the Institute would be appointing a very worthy successor to their retiring President.

The vote was carried with acclamation, and the new President took the chair.

Mr. **Robert Buchanan**: I thank you for your kindness in electing me to this important office. I can assure you I will leave nothing undone to increase the usefulness of the Institute, and to add to the wide prestige it already has. My first duty is the very pleasant one of proposing a vote of thanks to the retiring President. Those who have been brought in contact with him during the period he has held office will have been impressed by the ability he brought to bear in the exercise of his duties, not less than by his unvarying courtesy.

Mr. L. D. **Thomas** seconded the vote, which was carried unanimously.

Mr **William Somers**: I am very much obliged to you for the vote of thanks you have just passed, and to the President for the way in which he proposed it. It has been one of the greatest pleasures I ever had to preside over this Institute, and I shall always look back upon it as an honour.

The **President** proposed Mr. W. J. Foster as Vice-President for the ensuing year.

Mr. **James Piper** seconded, and it was passed unanimously.

The retiring Treasurer (Mr. **James Piper**) and Secretary (Mr. W. H. **Carder**) were re-elected.

Proposed by the President, seconded by Mr. T. E. Salter, and resolved that Messrs. William Somers, A. E. A. Edwards, and C. E. Edwards be elected to fill vacancies on the Council, and that the Council for the ensuing year consist of Messrs. Thomas Ashton, John Bate, William Brooks, Alfred Cookson, A. E. A. Edwards, C. E. Edwards, Richard Edwards, David Evans, Jno. W. Hall, W. H. B. Hatton, Geo. H. Head, Walter Jones, Rd. Lythgoe, Walter Macfarlane, Frank East Nurse, Wm B. Rubery, Harry Silvester, William Somers, Leyshon D. Thomas, Harry B. Toy, and Thomas Turner.

Proposed by the President, seconded by Mr. Jno. Keeling, and resolved that the members visit Rugby for the Annual Excursion on Wednesdav, the 19th June next, if that date is suitable to Messrs. Willans and Robinson, Ltd., and The British Thomas-Houston Co., Ltd., and that the Council be empowered to make all the necessary arrangements for the visit.

ANNUAL DINNER.

The Annual Dinner was afterwards held at the Station Hotel, the attendance being very large.

After the loyal toasts had been duly honoured, Mr. H. **Pilkington**, in proposing the toast of "The Iron, Steel, and Coal Trades," said that the prosperity of the respective three industries included in the toast might well have suggested a reversal of the order of the toast to "The Coal, Iron, and Steel Trades." The coalmasters were in a very comfortable position at date, and as a member of the iron trade he would like to appeal to them to use their power mercifully. There was one feature of the coal trade which was a source of much dissatisfaction to him, this was the enormous quantity of British coal which was being sent abroad to build up competing manufacturing industries. The least mischievous side of the export trade in coal was the circumstance that were it absent, the fuel for our own manufactures would probably be somewhat cheaper. Though it was not so marked as in the coal trade, there was also considerable prosperity in the iron and steel trades. Buyers, however, who were apt sometimes to chafe at the current higher prices, must not forget that these increased quotations on rolled iron and steel were not all profit. Manufactured iron and steelmasters had to bear an increased cost of raw materials. This increase had been so conspicuous that if producers of rolled iron and steel had not in many instances been bought forward in respect of raw materials, their position would have been very different from what it actually was. And to some extent the same remarks applied to the makers of pig iron also. If a cost sheet were struck on the present selling prices of materials he did not think the contemplation of the document would make manufacturers smile. The increased output of iron and steel the world over was very conspicuous. In 1906 the production of pig iron in the United Kingdom was more than 10,000,000 tons, in Germany the make was 12,500,000 tons, while in the United States the enormous total was touched of better than 25,000,000 tons, or double the make of Germany. It was a singular reflection—and a serious one, too—that at the date when that Institute was founded, only little more than forty years back, England had the greatest make of pig iron in the world. Now, as he had shown, we had subsided to the third place. Surely it was matter for anxious thought that during half the period of the life of that Institute the production of iron and steel in Great Britain had remained practically stationary. It might be thought by some that the world's production to-day was excessive. Sooner or later, however, no matter how great the production, demand overtook it; it had been so in the past, it would be so again. In 1866 the quantity of pig iron consumed per head of the population of the world was only 20lbs. Forty years later, namely, last year, the consumption per head had grown to 86lbs. Guaged by the quantity of iron consumed, the United States were still ahead of all other countries in civilisation, their consumption being something like 600lbs. per head of the population—a proportion far greater than that of any other nation. The figures which he had given of the production of iron were not satisfactory. Great Britain ought to possess a greater share of it. It was true we were under disadvantages compared with some of the countries he had mentioned. We were not fighting on equal terms—

he referred to economic terms—and it seemed to him that if the facts were not as he had suggested, we should be in a much better productive position than at present. The predominant manufacture of iron and steel was England's birthright, but we had allowed it to be stolen from us. England's make of pig iron ought to be double what it was at the present time, and we ought also to have taken our full share in the world's increased make of rolled iron and steel material. In conclusion, Mr. Pilkington said that the existing trade prosperity would be certain to be followed by a period of reverse conditions, and he suggested that manufacturers should pursue the necessary steps not to be taken by surprise. Germany and America were both overloading their requirements by the laying down of larger plants than there would be work for in a time of normal trade. British manufacturers might expect to see a resumption of the import of "dumped" materials.

Mr. George Hatton replied to the toast. He said that while Mr. Pilkington had spoken of the iron and steel trades of the country as a whole, he should confine himself mainly to the trade of South Staffordshire, as being perhaps of more immediate interest to their gathering. A divergence of opinion might be entertained respecting South Staffordshire's prospect. He himself, he was glad to say, was not a pessimist. The district had witnessed many changes during the last couple of decades, of which its decline in the manufacture of pig iron was one of the most conspicuous, the supply of this material being now very largely drawn from other and newer pig-making districts. There had also been a great decline in the practice of puddling, due to the substitution of steel for puddled iron; but this change was common to the industry the kingdom over. There was this difference, that in South Staffordshire the change had been emphasised by a removal of numbers of the sheet ironworks to the coast, particularly to South Wales, where the new raw material was more readily accessible. In spite of these extensive changes, however, South Staffordshire continued its career as a seat of iron and steel manufacture, and, he believed, would still continue it. To this extent, therefore, he confessed to being an optimist. One advantage which the district possessed was one which had often been pointed out, and which was of the greatest possible help, namely, the great diversity of its industries. This situation provided iron and steel masters with a large market close to their own doors, and he was glad to be able to say that he believed the diversity of trades would long continue with them. Another feature which must always minister to the well-being of South Staffordshire was its good supply of native fuel—a supply, too, which he heard from the Earl of Dudley's mining agents would soon become larger, by reason of his lordship's new colliery sinkings at Baggeridge, situate midway between Dudley and Wolverhampton. It was very gratifying and reassuring that the improvememt in trade which had characterised the iron and steel trades of the country as a whole now for over a year had been fully shared in by their own district. And he considered the immediate prospect was a very bright one. Changes from the present prosperity would come; of that there could be no doubt. But they would be common to the iron trade of the kingdom generally; South Staffordshire would not be alone in experiencing the turn in the tide. The existing good trade had not inherently originated at home, and it was here that the danger lay for the future. Recent revivals in this country had originated largely in an overflow of prosperity in Germany and the United States. Just in the same proportion on this occasion of revival, when demand in those countries flagged, trade here would slacken, and competition from Germany and America would recommence in the form of "dumped" imports. These imports would again be sold below cost. The nations named had reduced iron and steel manufacture to a fine art, and were immensely advantaged by their fiscal arrangements Mr Hatton said, however, that though he saw a resumption of foreign competition coming, and though its return migh temporarily dislocate British trade, he entertained no question that our iron and steel masters would successfully weather the onslaught. Speaking of helps to trade, he emphasised the call for improved waterways, particularly from the Midlands and other inland districts to the ports. In closing, he referred to the current "harassing legislation," and considered that much of it, in respect of trade and industry, was overdone and uncalled for.

ALDERMAN JOB GARRATT also replied. Commencing with a retort to Mr. Pilkington's suggestion of undue prosperity in the local coal trade, he said he did not find the state of the industry as good as Mr. Pilkington would have him believe. Ironmasters at that dinner would bear him out that recent iron trade prosperity had not in all instances meant increased prices; they had had a good many old contracts to work off. Well, it had been the same in the coal trade, so Mr. Pilkington's thrusts were not altogether exact. Mr. Jeans, of the Iron Trade Association, in his evidence before the Parliamentary Committee upon the proposed Eight Hours Working Day for miners, had just said that the coalfields of Lanarkshire and Staffordshire would be exhausted in about ten years. Speaking only of Staffordshire, if Mr. Jeans confined himself strictly to what used to be known as the old South Staffordshire coalfield, disturbing as the picture might be, he was perhaps not far wrong. But there was, he was glad to say, another side to the picture, and one which should afford that Institute infinite satisfaction. Mr. Jeans' calculation left out the great Sandwell and Hamstead coalfields on the West Bromwich side of South Staffordshire, where there was a large supply of still ungotten coal in the virgin state. More important than either of these perhaps, and more recent, were the new colliery sinkings at Baggeridge, of the Earl of Dudley, referred to by Mr. Hatton. These mines would probably last at least fifty years.

Then there were the Cradley and Cradley Heath and the Southern districts, both of which contained, according to Professor Lapworth—that eminent authority upon the British coalfields—1,000 acres of thick coal, besides the heathen and brooch measures. When this field was considered, there had yet to be added thousands of acres of thin coals yet ungotten even in the old South Staffordshire coalfield. They might, he believed, rest assured that the life of the coal of South Staffordshire was likely to extend to 100 years rather than to ten years. And when that hundred years had elapsed he had little fear that some other means would be devised for successfully meeting the raw-material needs of the great Staffordshire iron and steel industries. Concerning the thin seams he had just referred to in the old coalfield, these averaged from 20in. up to 3ft. thick, and when the necessity for more fuel arose, they would have to be got. They could not be worked, however, at a profit under present conditions, either of manual labour or of machine getting. What was needed—and he hoped that sometime or other the invention would be forthcoming—for the getting of these remnants was a mechanical coal cutter, which would take up not much more room than a working pikeman and not be higher than that dinner table, so low, indeed, that it could work under the table. The roofs of the pits where these thin seams existed were too rotten to make possible the employment of ordinary coal cutting machinery.

THE MAYOR OF DUDLEY (Mr- F. W. Cook) proposed the toast of "The Institute." Might it long continue to flourish. It augured well for the success of local industries when those engaged in ownership and management set themselves earnestly and patiently to solve the constantly recurring problems connected with their industries. To keep themselves abreast of the times was the duty of all. Indeed, in times of International strain and stress like the present, it was the only way to succeed—he had almost said exist. *Progress was the very life blood of* trade. The expansion of iron and steel manufacture in the last fifty years had been phenomenal, and it was a proud thing for the Institute to recall that many of the pioneers in the trade had been born and trained in that district. His worship had strong faith that there were men in that Institute and in Staffordshire, to-day, who would still go forward and again carry the name of Staffordshire to the very forefront of the industry. British manufacture, to be successful, needed all the help that science, both theoretical and applied, and practical [illegible] knowledge could render. In this connection the periodic visits which the Institute paid to works connected with the iron and steel and engineering and allied industries in other districts should be of [illegible] assistance. His worship commented upon the services which chemistry and [illegible] to the iron and steel trades in the utilisation of previously waste products, and said he should not be surprised if ultimately a use should be found not only for our furnace slag heaps but also for our colliery spoil mounds. America, with her trusts and combines, might yet teach the other manufacturing nations useful lessons, and not least, perhaps, the necessity for superseding some of our old ideas pointing to individualism and insolation in manufacturing production by broader and more common-interest principles. In conclusion, the speaker said that for centuries Staffordshire had been a centre of iron and steel manufacture. It was for the Institute, as representing all that was best in technical and scientific attainment in the district, to see to it that its development continued. The interests of the industry must be watched over zealously, and the existence of nothing that hindered further expansion must be tolerated.

The President, in replying to the toast, said that the Institute had exerted a great influence on the practice of iron and steel manufacture in South Staffordshire. More than this, the trades and industries represented by the membership were of great variety, and the accumulated knowledge of the members was an absolute industrial asset. In face of such a record, he was somewhat surprised at the pessimistic views sometimes expressed at their meetings. Such a tone was to be deprecated, especially if they considered the unfortunate influence it might have upon the energies of the younger members. That district had had some great times in the past, and he failed to recognise any sufficient reason why these good times should not recur The President proclaimed himself always a hopeful man, and said he hoped that during his year of office the spirit of conscious power would always be uppermost in their discussions. There was energy and assiduity, he believed, amongst the younger men in the district to carry them anywhere. Courage was the finest quality in the world. He believed that for the practical skill of its iron and steel masters and managers, Staffordshire still ranked as the highest ironmaking centre in the Kingdom, and its possibilities of technical and theoretical knowledge had of late years been greatly added to, especially since the founding of Birmingham University. The native ironfields were not so redundant as formerly, but the iron-ore deposits of Northampton and Derbyshire and Lincolnshire had come to the rescue, and by the aid of these South Staffordshire was still holding its own. He was very confident of the future. Ways and means must be found whereby the prosperity of this centre would be maintained. He believed it would be impossible for any of the competing iron districts to permanently submerge the Midlands. In the work of maintenance the Institute was destined to play an important and honorable role.

Mr. H. Silvester gave "Kindred Associations," and suggested the holding of combined meetings of the various technical associations of the district, at which papers of common interest might be presented.

Mr. T. H. Dacres, President of the Birmingham Association of Mechanical Engineers, acknowledged the toast.

BALANCE SHEET,

FOR YEAR ENDING 31st DECEMBER, 1906.

Dr.	£	s.	d.	Cr.	£	s.	d.
To Balance brought forward	126	4	2	By Expenses at Annual Meeting	10	5	8
„ Subscriptions	158	15	6	„ Printing and Stationery	61	11	6
„ Books and Papers Sold	1	2	6	„ Shorthand Notes	6	11	6
„ Interest on Invested Funds	3	8	6	„ Postages and Telegrams	16	13	1
				„ Carriage and Sundry Expenses	5	4	7
				„ Book Cupboard	4	5	0
				„ Rent	8	0	0
				„ Secretary's Honorarium	20	0	0
					132	11	4
				Invested at 2½ per cent., £119 1 1 In Treasurer's hands, £ 37 18 3	156	19	4
	£289	10	8		£289	10	8

Examined with Vouchers and found correct this 26th day of April, 1907.

WALTER W. PAGETT,
JAMES RAYBOULD, } AUDITORS.

RULES.

REGISTERED No 943. WORC.

1.—The Society shall be designated "The Staffordshire Iron and Steel Institute. Its registered office is in England, and is at the Institute, Wolverhampton Street, Dudley, in the County of Worcester. In the event of any change in the situation of the registered office, notice of such change shall be sent within fourteen days thereafter to the Registrar, in the form prescribed by the Treasury Regulations in that behalf.

2.—This Society is subject to the provisions of the Friendly Societies' Act, 1875, except so much thereof as relates to dividing societies (section 11, sub-section 4); the certification of annuities (section 11, sub-section 5); appeals from a refusal to register a society or any amendment of the rules thereof (section 11, sub-sections 8 and 9, and section 13, sub-section 3); or from cancelling or suspension of registry (section 12, sub-section 4 and part of sub-section 5); quinquennial returns and valuations (section 14, sub-section 1, *e f*); certificates of death (section 14, sub-section 2, and section 15, sub-section 9), exemption from stamp duty (section 15, sub-section 2); nomination and distribution (section 15, sub-sections 3, 4, and 5); priority on death, bankruptcy, &c., of officers (section 15, sub-section 7), copyholds (section 16, sub-section 6); loans to members (section 18); the accumulation of surplus of contributions for members' use (section 19); so much of section 22 as relates to the reference of a dispute to the chief or any other Registrar; the amalgamation, transfer of engagements, and dissolution of Friendly Societies (section 24, proviso to sub-section 8, and section 25, sub-section 1, *c*, and sub-section 7); militiamen and volunteers (section 26); the limitation of benefits (section 27); payments on the death of children (section 28); societies receiving contributions by collections (section 30); cattle insurance and certain other societies (section 31); and the four last heads of Schedule II.

3. -The objects of the Institute are:—To promote the intellectual welfare of its members by periodical meetings for reading and discussing scientific papers on subjects connected with the Iron and Steel Trades, and such other matters as may be considered within the scope of the special authority of 3rd July, 1878 ("The Promotion of Literature, Science, and Fine Arts.") The expenses incurred in carrying out the

above objects shall be provided by the subscriptions of Life and Honorary Members, the entrance fees and periodical contributions of Ordinary Members, and from interest upon any accumulated capital.

CONSTITUTION.

4.—The Institute shall consist of Life, Honorary, and Ordinary Members, who shall be more than twenty-one years of age, and shall be either owners, managers, assistant managers, and other officials of iron and steel works, mechanical or mining engineers, analytical chemists, draughtsmen, or persons of scientific attainments in metallurgy, or specially connected with the application of iron and steel.

HONORARY MEMBERS.

5.—Any person connected with the Iron and Steel Trades may, on the invitation of the Secretary or any other officer become an honorary Member of the Institute, on payment of One Guinea yearly to its funds, such payment to entitle him to receive invitations to all meetings of the Institute, and copies of all its publications. Any Honorary Member may become an Hon. Life Member by the payment of Ten Guineas.

ELECTION OF ORDINARY MEMBERS.

6.—Any person desirous of becoming an Ordinary Member of the Institute must be proposed according to Form A in the Appendix, and the form sent to the Secretary and by him laid before the next meeting of the Council. The name, occupation, and address of each candidate whose nomination has been approved by the Council, together with the names of his proposers, shall be printed in or sent with the circular convening the next Ordinary Meeting.

7.—The election shall take place at an ordinary meeting; a two-thirds majority of the members present being necessary for election.

8.—When the proposed candidate is elected, the Secretary shall give him notice thereof, according to Form B; but his name shall not be added to the list of members of the Institute until he shall have paid his entrance fee and first annual subscription, and signed Form C in the Appendix.

9.—In the case of non-election, no mention thereof shall be made in the minutes, nor any notice be given to the unsuccessful candidate.

SUBSCRIPTIONS.

10.—The Subscription for an Honorary Member shall be One Guinea per annum, and for an Honorary Life Member Ten Guineas, as provided by Rule 5. Each Ordinary Member shall pay an entrance fee of Two Shillings and Sixpence and an annual subscription of Ten Shillings and Sixpence; or he may become an Ordinary Life Member by the payment of Five Guineas. All annual subscriptions shall be payable in advance, and shall be due on the First day of January in each year.

11.—Any member whose subscriptions shall be two years in arrear shall be thereby disqualified, and the Council, after having given due notice, in the form D. in the Appendix, shall remove his name from the list of members, unless satisfactory reasons are given to the contrary.

OFFICERS.

12.—The officers of the Institute shall consist of a President, a Vice-president, Twenty-one Members of the Council, Three Trustees, a Treasurer, and a Secretary, who shall be elected at the annual meeting by show of hands. The President, Vice-president, Treasurer, and Secretary, shall be *ex-officio* members of the Committee of Management, herein termed Council. Officers may be removed by a special general meeting.

13.—In addition to the *ex-officio* members, the Council shall consist of Twenty-one members, all of whom shall retire annually, but shall be eligible for re-election, with the exception of those who have not attended any of the Council meetings called during the year for which they have been elected.

14.—The Council shall meet as often as the business of the Institute requires; seven to form a quorum. Such meetings to be called by the Secretary, of which seven clear days' notice shall be given.

15.—The Council shall appoint from its own body two Committees, one to be called the Finance Committee, which shall advise the Council on matters relating to the receipts and expenditure of the Institute; and the other to be called the Publication Committee, which shall arrange for suitable papers to be read at the meetings of the Institute, and shall undertake the revision of all printed transactions. The Council shall provide the Secretary with a sufficient number of copies of the Rules to enable him to deliver to any person on demand a copy of such rules, on payment of a sum not exceeding One Shilling; and it shall be the duty of the Secretary to deliver such copies accordingly.

DUTIES OF OFFICERS.

16.—The President shall be chairman at all meetings at which he shall be present, and in his absence the Vice-president. In the absence of the Vice-president, the members shall elect a chairman for that meeting.

17.—The Treasurer shall hold in trust the uninvested funds of the Institute, which shall be deposited at a bank approved by the Council; he shall receive from the Secretary all amounts paid by way of subscription, contribution, or payment; and shall pay all accounts that are properly certified as correct by the President and Secretary, He shall keep proper books of account. and shall submit them once a year, or oftener if required by the Council, to the Auditors appointed, and shall supply the Secretary with a duplicate copy of his balance sheet.

18.—The Secretary shall attend all meetings, carry on the general business and correspondence of the Institute, arrange meetings for the reading of papers and for other purposes, and keep minutes of all proceedings, which shall be authenticated by the signature of the Chairman. He shall collect all subscriptions and pay the same to the Treasurer, and shall prepare and send the Returns required by the Friendly Societies Acts and the Treasury Regulations to be sent to the Registrar. He shall be paid an honorarium on March 25th in each year, in addition to any sums he may expend on behalf of the Institute for postages, stationery, printing, or travelling expenses.

19.—The Trustees, each of whom must be a householder, and in whose names the properties and surplus funds of the Institute shall be invested, shall continue in office during the pleasure of the Institute, and in the event of any of them dying, resigning, or being removed from office, another or others shall be elected at the next general meeting of the Institute. A copy of every resolution appointing a Trustee shall be sent to the Registrar within fourteen days after the date of the meeting at which such resolution was passed, in the form prescribed by the Treasury Regulations in that behalf.

MEETINGS.

20.—The Annual Meeting shall be held in April in each year.

21.—General Meetings shall be held as often as business requires. The place of such meetings to be decided at the previous annual meeting.

22.—The President or the Council, in case he or they at any time think it necessary, or the President, on the requisition of six members, may convene a Special General Meeting of the Institute, for the consideration of any subject requiring the immediate attention of members. The business of such meeting shall be confined to the special subject named in the notice convening the same.

23.—All members shall have at least six clear days' notice of, and be entitled to attend, each meeting of the Institute, and to receive copies of the Institute's publications gratuitously.

24.—No alterations of the Rules shall be made except at a general meeting, and four weeks notice in writing must be given to the Secretary of any proposed alterations. No amendment of Rules is valid until registered.

AUDITORS.

25.—The accounts, together with a general statement of the same and all necessary vouchers, up to the 31st December then last, shall be submitted once in every year to two auditors, appointed by the members at the general meeting preceding each annual meeting, who shall lay before every such meeting a balance sheet (which either may or may not be identical with the annual return, but must not be in contradiction to the same), showing the receipts and expenditure, funds and effects of the Institute, together with a statement of the affairs of the Institute since the last meeting, and of their then condition. Such auditors shall have access to all the books and accounts of the Institute, and shall examine every balance sheet and annual return of the receipts and expenditure, funds and effects of the Institute, and shall verify the same with the accounts and vouchers relating thereto, and shall either sign the same as found by them to be correct, duly vouched, and in accordance with law; or shall specially report to the meeting of the Society before which the same is laid in what respects they find it incorrect, unvouched, or not in accordance with law; and the balance sheet or report shall be published in the *Proceedings* of the Institute.

COMMUNICATIONS OF MEMBERS AND OTHERS.

26.—All communications shall be submitted to the Council, and after their approval, shall be read at the general meetings. All communications shall be the property of the Institute, and shall be published only in the *Proceedings* of the Institute, or by the authority of the Council.

PROPERTY OF THE INSTITUTE.

27.—All books, communications, drawings, and the like shall be accessible to all the members. The Council shall have power to deposit the same in such place or places as may be considered most convenient for the members.

INVESTMENT OF FUNDS.

28—As much of the funds of the Institute as may not be wanted for immediate use, or to meet the usual accruing liabilities, shall, with the consent of the Council, or a majority of the members of the Institute, present at a general meeting, be invested by the Trustees in such of the following ways as the Council or General Meeting shall direct, namely, in the Post Office Savings Bank, in the Public Funds, or with the Commissioners for the reduction of the National Debt, upon Government or real securities in Great Britain, or upon the security of any County, Borough, or other rates authorised to be levied or mortgaged by Act of Parliament.

ANNUAL AND OTHER RETURNS.

29.—It shall be the duty of the Committee of Management to keep a copy of the last annual balance sheet of the Society for the time being, together with the Report of the Auditors, if any, always hung up in a conspicuous place at the registered office of the Society—Friendly Societies Act, 1875, s. 14 (1 *i*.)

30.—The books and accounts of the Society shall be open to the inspection of any member or person having an interest in the funds of the Society at all reasonable times, at the registered office of the Society or at any place where the same are kept, and it shall be the duty of the Secretary to produce them for inspection accordingly.

31.—Every year before the 1st June, the Committee of Management shall cause the Secretary to send to the Registrar the annual return, in the form prescribed by the Chief Registrar of Friendly Societies, required by the Friendly Societies Act, 1875, of the receipts and expenditure, funds and effects of the Society, and of the number of members of the same, up to the 31st December then last inclusively, as audited and laid before a general meeting, showing separately the expenditure in respect of the several objects of the Society, together with a copy of the Auditors' report, if any.

32.—Such return shall state whether the audit has been conducted by a public auditor appointed under the Friendly Societies Act, 1875, and by whom, and if such audit has been conducted by any persons other than a public auditor, shall state the name, address, and calling or profession of each of such persons, and the manner in which, and the authority under which. they were respectively appointed.—Friendly Societies Act, 1875, s. 14 (1 *d*.)

33.—It shall be the duty of the Committee of Management to provide the Secretary with a sufficient number of copies of the annual return or of some balance sheet, or other document duly audited, containing the same particulars as in the annual return as to the receipts and expenditure, funds and effects of the Society, for supplying gratuitously every member or person interested in the funds of the Society, on his application, with a copy of the last annual return of the Society, or of such balance sheet or other document as aforesaid, for the time being, and it shall be the duty of the Secretary to supply such gratuitous copies on application accordingly.—Friendly Societies Act, 1875, s. 14 (1 *h*).

DISSOLUTION.

34.—The Society may at any time be dissolved by the consent of three-fourths of the members, including honorary members, if any, testified by their signatures to some instrument of dissolution in the form provided by the Treasury Regulations in that behalf.

DISPUTES.

35.—If any dispute shall arise between a member, or person claiming through a member, or under the Rules of the Society, and the Society, or any officer thereof, it shall be referred to justices pursuant to the Friendly Societies Act, 1875, s, 22 (*c*.)

APPENDIX.

FORM A.

THE STAFFORDSHIRE IRON AND STEEL INSTITUTE.

Mr.

of

being of full age and desirous of becoming a member of The Staffordshire Iron and Steel Institute, we, the undersigned, from our personal knowledge, do hereby recommend him for election.

His qualifications are

Witness our hands this day of 190

} Names of two members.

If elected a member of The Staffordshire Iron and Steel Institute, I, the undersigned, do hereby engage to ratify my election by signing the Form of Agreement (C) and paying the Entrance Fee and Annual Subscription in conformity with the Rules.

Witness my hand this day of 190

FORM B.

THE STAFFORDSHIRE IRON AND STEEL INSTITUTE.

To

Sir,

I beg to inform you that on the
you were elected a member of The Staffordshire Iron and Steel Institute, but in conformity with the Rules, your election cannot be confirmed until the accompanying form be returned with your signature, together with your Entrance Fee and first Annual Subscription. (Amount, £ s d.)

If this amount be not received in one month from this date, your election will become void.

I am, Sir,
Yours truly,
Secretary.

day of 19

FORM C.

THE STAFFORDSHIRE IRON AND STEEL INSTITUTE.

I, the undersigned, being elected a member of the Staffordshire Iron and Steel Institute, do hereby agree that I will be governed by the rules of the Institute, and that I will advance its interests as far as may be in my power. Provided that if I signify in writing to the Secretary that I am desirous of withdrawing my name therefrom, I shall (after paying all arrears which may be due by me at that period) be free from this obligation.

Witness my hand this day 19

Member's Signature.

FORM D.

THE STAFFORDSHIRE IRON AND STEEL INSTITUTE.

Dear Sir,

I am directed by the Council to inform you that your subscription to the Institute, amounting to
is still in arrear, and that if the same be not paid to me on or before the day of your name will be removed from the lists of the Institute.

Yours faithfully,

Secretary.

OFFICERS FOR SESSION 1907-1908.

President:

ROBERT BUCHANAN.

Vice-President:

WILLIAM J. FOSTER.

Trustees:

ALFRED COOKSON, MOSES MILLARD, WILLIAM B. RUBE

Treasurer:

JAMES PIPER.

Council:

THOMAS ASHTON
JOHN BATE
W. BROOKS
ALFRED COOKSON
A. E. A. EDWARDS
C. E. EDWARDS
RD. EDWARDS
DAVID EVANS
J. W. HALL
W. H. B. HATTON
G. H. HEAD
WALTER JONES
R. LYTHGOE
WALTER MACFARLA
FRANK EAST NURS
W. B. RUBERY
HARRY SILVESTER
WM. SOMERS
LEYSHON D. THOM
H. B. TOY
THOMAS TURNER

Secretary:

WILLIAM H. CARDER, 158, Tividale Road, Tipton.

PAST PRESIDENTS.

WILLIAM LESTER
JOHN BROWN
JOHN WRIGHT
SAMUEL NEWTON
WILLIAM EDWARDS
JOHN FINNEMORE
AMBROSE BEARDS
JOHN FIELDHOUSE
WILLIAM MOLINEAUX
HENRY HUGHES
WILLIAM FARNWORTH
JOHN WRIGHT
WALTER HEELEY
JAMES RIGBY
EDWARD HARRIS
JOSEPH MORRIS
RICHARD EDWARDS
MOSES MILLARD
WILLIAM JNO. HUDSON
RICHARD SMITH CASSON
HENRY FISHER

1887—GEORGE B. WRIGHT
1888—HENRY PARRY
1889—ALEXR. E. TUCKER
1890—HERBERT PILKINGTON
1891—HERBERT PILKINGTON
1892—THOMAS TURNER
1893—JAMES ROBERTS
1894—THOMAS ASHTON
1895—WILLIAM B. RUBERY
1896—WILLIAM YEOMANS
1897—JNO. W. HALL
1898—H. LE NEVE FOSTER
1899—HARRY SILVESTER
1900—LEYSHON D. THOMAS
1901—WALTER SOMERS
1902—WALTER SOMERS
1903—WALTER SOMERS
1904—HARRY B. TOY
1905—WALTER JONES
1906—WILLIAM SOMERS

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"Iron and Steel Trades Journal."
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They are also presented to the Library of the Patent Office, London, and the Library of the University, Birmingham.

INDEX.

Allen, Horace, on Professor Burstall's paper 70
Analysis of Produced Gases 36
Annual Dinner 135
„ Meeting 133
Applications of Produced Gas to Furnaces 42
„ „ Steam Turbine 103
Apprenticeship system 4
Ashton, Thomas, on Dr. Findlay's paper 100
Assessments 8
Attwood, E. J., elected member 30
Auditors, appointment of 112

Baker, W., elected member 1
Balance Sheet 141
Birkinshaw, W. G., on Mr. Wall's paper 55
Bischof Producer 33
Blast Furnace, the, practically and theoretically considered 113
Blow Pipe Furnaces 44
Buchanan, Robert, on Professor Burstall's paper ... 74
„ „ „ Mr. Noel's paper 111
„ „ „ Mr. Foster's paper 128
„ „ elected President 134
Burstall, Professor, F. W., on Internal Combustion Engines 61
„ „ „ Reply to discussion on his paper 75
Bush, E. J., elected member 1

Canals, ownership of 7
Carder, W. H., on Mr. Noel's paper 107
Chemistry, physical, some principles of, in their application
in Metallurgy 78
Combined influence of certain elements in Cast-iron ... 18
Cooke, H. H., elected member 30
Council, Annual Report of 133
„ Election of 135
Crossley Engines 63

De Laval Turbines 103
Dowson, E. A., on Mr. Wall's paper 53
,, ,, ,, Professor Burstall's paper 74
,, ,, ,, Mr. Noel's paper 109
Dudley Chamber of Commerce 60
Dudley, Mayor of, on the Institute 139

Ebelman's Producer 33
Economies in Works... 9
Edwards, A. E. A., on Mr. Wall's paper 51
Ekman's Producer 33
Engines—internal combustion 61
Evans, David, on Mr. Foster's paper 130
Exchanges, List of 170

Fell, C., elected member 30
Fellows, T. K., elected member 1
Fennell, W., on Professor Burstall's paper 72
Findlay, Dr. Alex., on some principles of physical chemistry
in their application in metallurgy 78
Findlay, Dr. Alex., Reply to Discussion on his paper ... 100
Fletcher, J. Ernst, elected member 30
,, ,, on Dr. Findlay's paper 98
Foster, W. J., on Mr. Wall's paper 56
,, ,, ,, the Blast Furnace, practically and theoretically considered 113
Foster, W. J., Reply to Discussion on his paper ... 131
,, ,, Elected Vice-president 135
Fuel, economy of 46
Furnaces, application of producer gas to 42

Garratt, Job, on the Coal Trade 138
Gas Engines 61
Gaseous Fuel 35
Gas Producer, introduction of 33
,, ,, theory of 31
,, ,, analysis of 36
Gas, use of for heating and re-heating furnaces ... 31
Gibbs, G. H., on Professor Burstall's paper 72

Gibbs, G. H., on Mr. Foster's paper 126
Glasses and Slags 83
Groocock, C. B., elected member 17
Guldner Gas Engine 68
Guyatt, D. J , elected member 30

Hall, Jno. W. on President's Address 13
„ „ „ Professor Burstall's paper 68
Harris, Samuel, elected member 17
Hatton, Geo., on Iron Trade 137
Heyn, Professor, on constitution of Iron and Carbon Alloys 19
Hiorns, A. H., on the combined influence of certain elements on Cast-iron 18
Honour, A E., elected member 102
Hudson, O. F., on Dr. Findlay's paper 100

Ignition of Gas Engine Charges 64
Internal Combustion Engines 61
Iron and Carbon, relations of 94
Iron and Coal Trades, condition of 135

Jones, Walter, on President's Address 10
„ „ „ Mr. Wall's paper 48
„ „ „ Professor Burstall's paper 71
„ „ „ Mr. Foster's paper 127

Keeling, Richard, elected member 30
Kendrick, W., on President's Address 15
„ „ „ Mr. Foster's paper 129

Lodge ignition, apparatus, the 64

Mace, C. F., elected member 30
Manganese, influence of 19
„ and Phosphorus 23
„ and Silicon 22
„ and Sulphur 25
Members, List of 152
Mercer, R. G., on Professor Burstall's paper 72

Moore, Samuel, elected member 1
„ „ on Mr. Noel's paper 110

Noel, F., on Some Applications of the Steam Turbine ... 103

Officers, Election of 135
„ List of 150

Page, F. W., on Mr. Wall's paper 55
Parsons Turbine, the... 103
Past Presidents, List of 151
Phase Rule, the 80
Phosphorus, influence of 21
„ and Silicon 27
„ and Sulphur 28
Physical Chemistry, some principles of in their application in Metallurgy 78
Pilkington, H., on Iron and Coal Trades 135
Pinnock, H. T., on Dr. Findlay's paper 99
Piper, James, on President's Address 14
Premier Gas Engines, the 63
President, Address by 2
„ Reply to Discussion 15
„ on Mr. Wall's paper 48
„ on Mr. Foster's paper 130
„ Vote of thanks to 135
Producer Gas, analysis of 36

Rollason, J., elected member 1
Rules 142

Scott, E. M., elected member 30
Siemens Producer, the 34
Silicon, influence of 18
„ and Sulphur 26
Siviter, H., on Mr. Foster's paper 129
Somers, Frank, on Mr. Wall's paper 52
„ „ „ Mr. Noel's paper 109
Somers, William—see President

Stanier, C. E., elected member 17
„ „ on Mr. Wall's paper 54
Steam Turbines 103
Sulphur, influence of 20

Thomas, L. D., on President's Address 14
Turbine, some applications of the.. 103
Turner, Professor, on Dr. Findlay's paper 97

Wall, C. H., on the use of gas for heating and re-heating furnaces 31
Wall, C. H., Reply to Discussion on his paper ... 56
Wesson, W., elected member 30
Westinghouse Engines 65
Whitehouse, Geo., elected member 30
Willans Turbine 104
Wilkinson, F. S., elected member... 1
Wood, F., elected member 1

r. A. H. Hiorns' Paper on the Combined Influence of Certain Elements on Cast-iron.

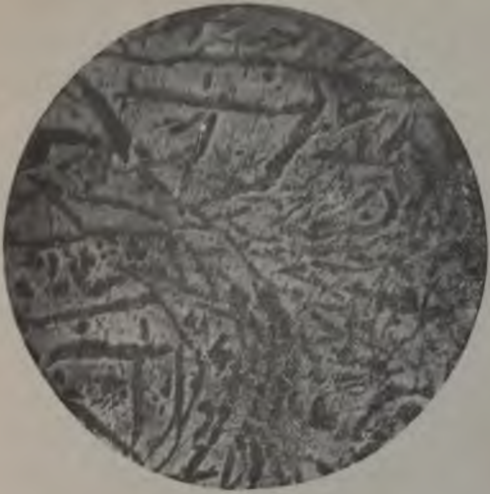

FIG. 1.

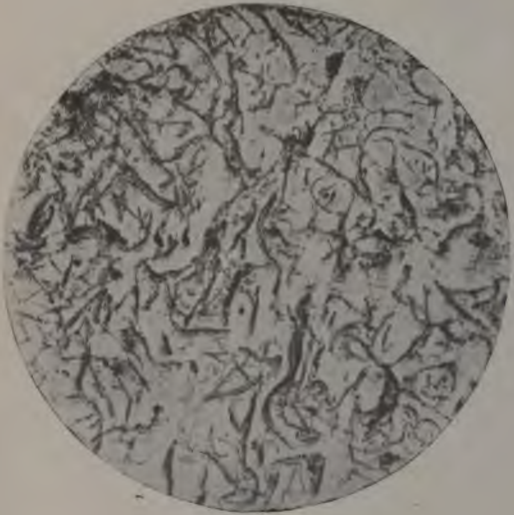

FIG 2.

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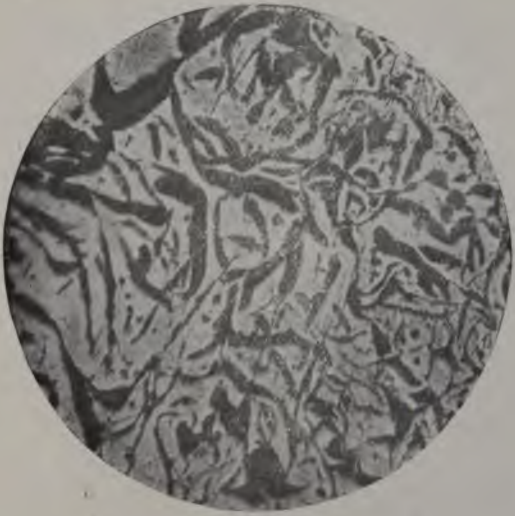

FIG. 3.

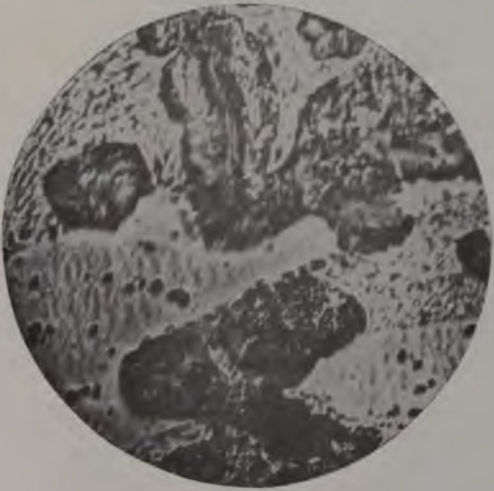

FIG. 4.

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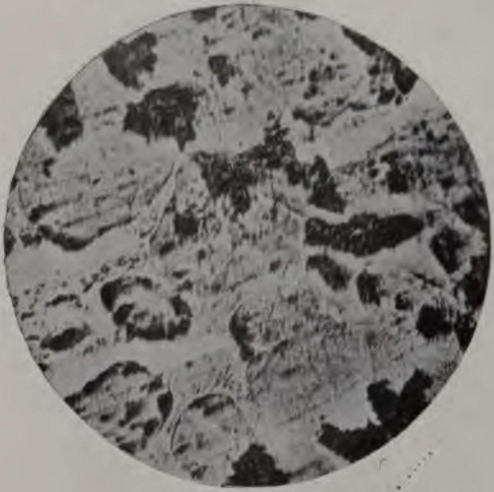

FIG. 5.

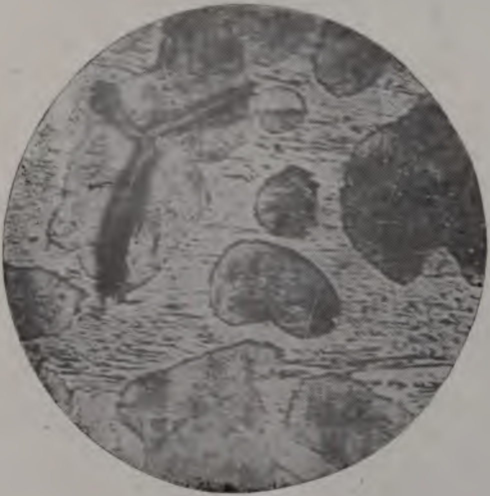

FIG. 6.

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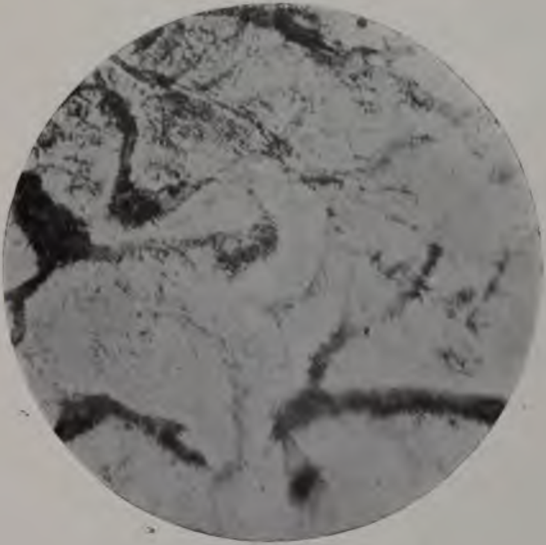

FIG. 7.

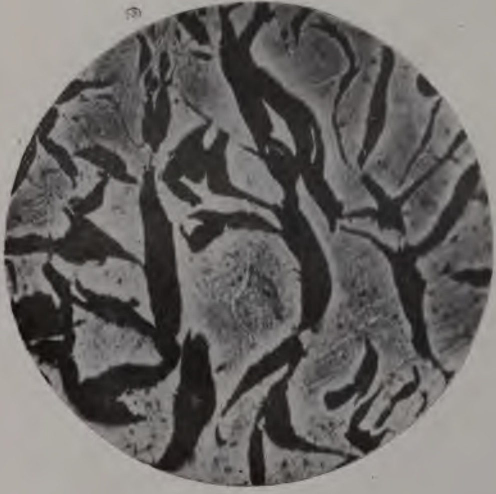

FIG. 8.

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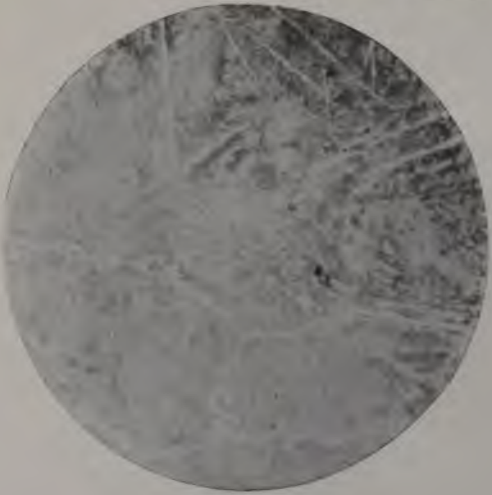

FIG. 9.

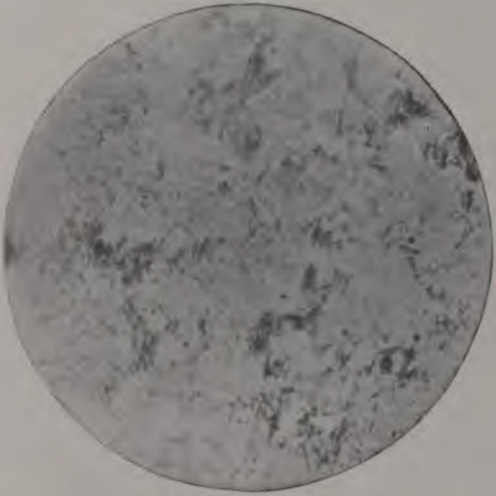

FIG 10.

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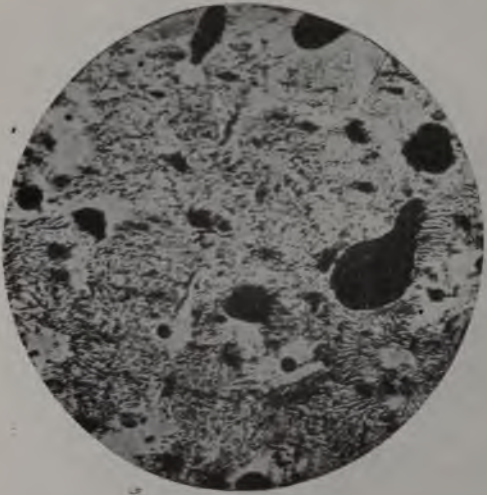

FIG. 11.

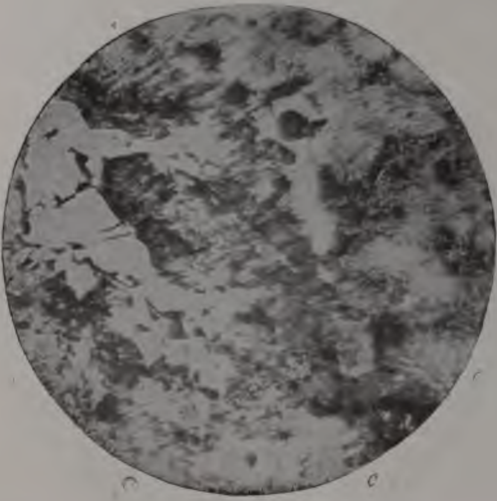

FIG. 12.

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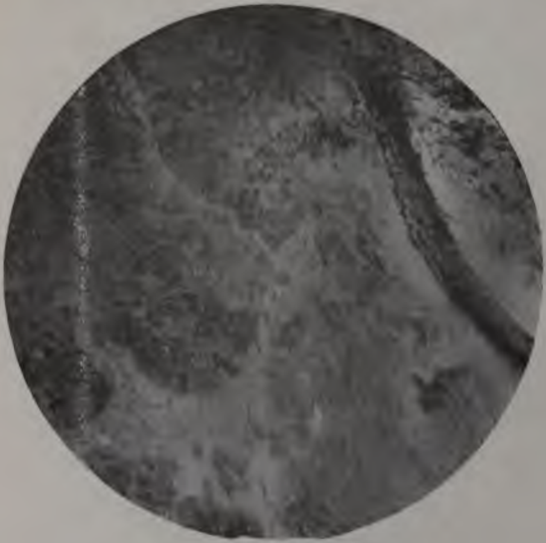

FIG. 13.

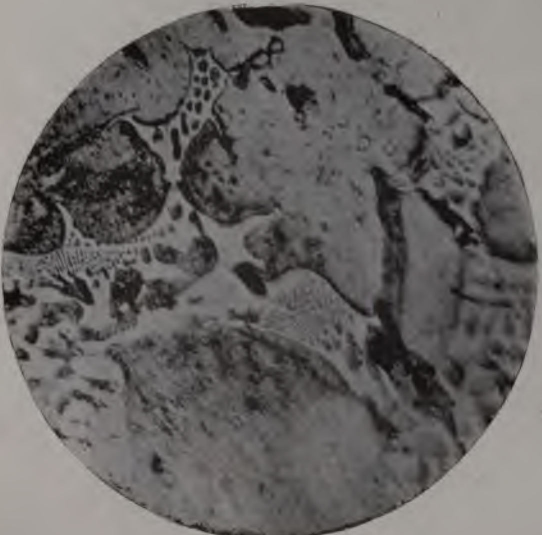

FIG. 14.

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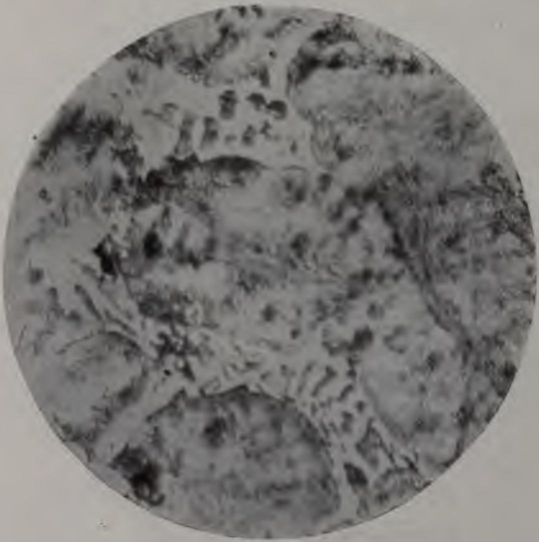

FIG 15.

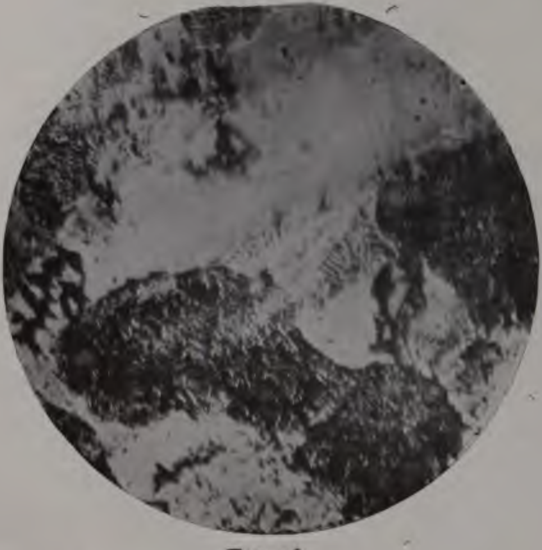

FIG. 16.

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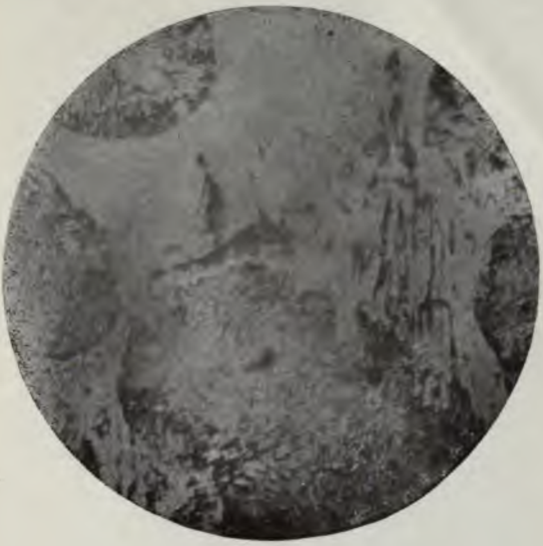

FIG. 17.

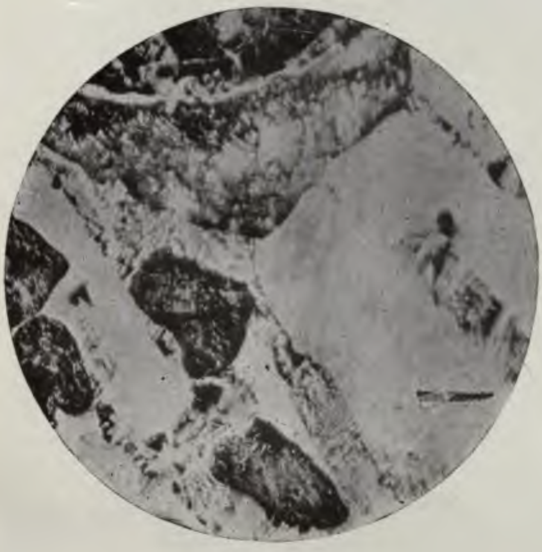

FIG 18.

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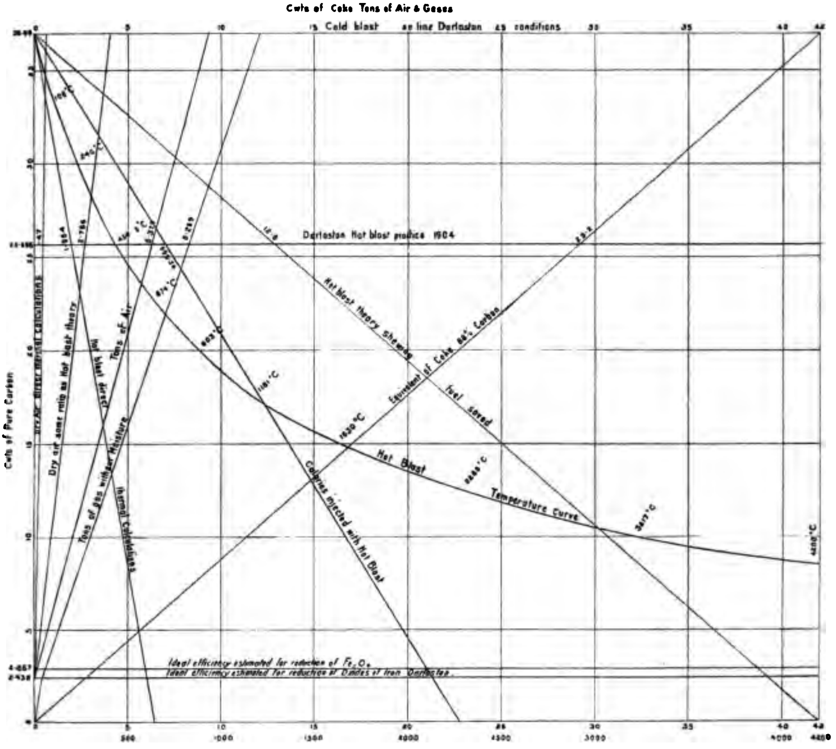

Cwts. of Coke, Calories, and Degrees Centigrade.

The reason for estimating the carbon zero which is shewn to be required at Darlaston to reduce the Oxides of Iron present in the charge, is reduced from 2·857 to 2·438 on account of introducing a certain amount of scrap into the charge, which proved to be equivalent to 23·04 tons of Oxygen to 70·9 tons of Iron charged, while on the other hand Fe_3O_4 as described in the paper would account for 27 tons of Oxygen per 70.9 tons of Iron charged thus—Fe_3O_4.

$$186 : 64 :: 70{\cdot}9 : 27 \qquad \therefore \overset{O}{27} : \overset{C}{2{\cdot}857} :: \overset{O}{23} : \overset{C}{2{\cdot}438}$$

The gases at zero should be .45 tons, because 70·9 tons of Fe is equivalent to 23·04 of O, therefore 1 ton of Iron is equivalent to ·324 of Oxygen, thus—

$$70{\cdot}9 : 23 :: 1 : {\cdot}324 \qquad \therefore \overset{O_2 + C = CO_2}{32 : 12 :: {\cdot}324 : {\cdot}126} \qquad \therefore {\cdot}324 + {\cdot}126 = {\cdot}450$$

Cwts. of gases from pure Carbon and Oxygen only.

SEP 1 9 [illegible]